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PROCEEDINGS OF A SEMINAR ON

# WATER QUALITY EVALUATION

22 - 24 JAN 1980
TAMPA, FLORIDA

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Topics addressed during the seminar included Corps policy, monitoring network design, oxygenation, thermal and turbidity studies. Other topics included site preparation, dredge material disposal, and gas transfer characteristics of hydraulic structures.

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ON

WATER QUALITY EVALUATION.

22-24 January 1980,
Tampa, Florida.

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U.S. ARMY CORPS OF ENGINEERS

COMMITTEE ON WATER QUALITY

WASHINGTON, D.C.

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# FOREWORD

A two-day seminar on Water Quality Evaluation was held in Tampa, Florida, on 22-24 January 1980. The purpose of the seminar was to provide a forum for Corps of Engineers personnel who are routinely involved in water quality evaluation. Topics addressed during the seminar included Corps policy, monitoring network design, oxygenation, thermal and turbidity studies. Other topics included site preparation, dredge material disposal, and gas transfer characteristics of hydraulic structures. Twenty-five papers presented during the seminar are contained herein.

The conference room, individual rooms and all local tour arrangements were organized by Mr. Julian Raynes from the South Atlantic Division office with the invaluable assistance of Mr. Willie Canaday of the Tampa Area Office.

These seminar proceedings in addition to the general seminar coordination were organized by Mr. R. G. Willey of the Hydrologic Engineering Center. The seminar was co-sponsored by the Hydrologic Engineering Center and the Committee on Water Quality.

The views and conclusions expressed in these proceedings are those of the authors and are not intended to modify or replace official guidance or directives such as engineer regulations, manuals, circulars, or technical letters issued by the Office of the Chief of Engineers.

R. G. Willey
Editor

SEMINAR ON

WATER QUALITY EVALUATION

22-24 January 1980
Tampa, Florida

Committee Members

| | |
|---|---|
| Dr. Mark Anthony | Ohio River Division |
| Charles Bradshaw | Lower Mississippi Valley Division |
| John Bushman | Office of the Chief of Engineers<br>Planning Division |
| Dick DiBuono | New England Division |
| Harry Dotson | South Pacific Division |
| Earl Eiker | Office of the Chief of Engineers<br>Engineering Division |
| Dr. Rex Eley | Waterways Experiment Station<br>Environmental Laboratory |
| Jim Gottesman | Office of the Chief of Engineers<br>Construction-Operations Division |
| John Grace | Waterways Experiment Station<br>Hydraulics Laboratory |
| Dr. Albert Holler * | South Atlantic Division |
| Dave Legg | North Pacific Division |
| Tom Maisano | North Atlantic Division |
| Dr. Harlan L. McKim | Cold Regions Research and<br>Engineering Laboratory |
| Ms. Jan Rasgus | North Central Division |
| Howard Reese | Missouri River Division |
| Charles Sullivan | Southwestern Division |
| R. G. Willey | The Hydrologic Engineering Center |

* Dr. Holler has recently replaced Julian Raynes who served on the Committee from its inception until his retirement.

## Seminar Speakers

| | |
|---|---|
| Mr. Dave Buelow | New England Division |
| Mr. Dick Cassidy | Portland District |
| Mr. Mann Davis | Jacksonville District |
| Mr. Earl Eiker | Office of the Chief of Engineers<br>Engineering Division |
| Mr. Glenn Drummond | Ohio River Division |
| Mr. John Dryden | Jacksonville District |
| Mr. John Grace | Waterways Experiment Station<br>Hydraulics Laboratory |
| Mr. Al Harrison | Missouri River Division |
| Mr. Bob Hopman | North Pacific Division |
| Mr. Richard Jackson | Wilmington District |
| Mr. Mike Koryak | Pittsburgh District |
| Mr. Paul Lang | Buffalo District |
| Dr. Jerry Mahloch | Waterways Experiment Station<br>Environmental Laboratory |
| Mr. N. D. McClure | Mobile District |
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| Mr. Randy Miller | Savannah District |
| Mr. Joseph L. Norton | Waterways Experiment Station<br>Environmental Laboratory |
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| Dr. Bob Pierce | North Atlantic Division |
| Ms. Jan Rasgus | North Central Division |
| Mr. Howard Reese | Missouri River Division |
| Dr. Lloyd Saunders | Jacksonville District |
| Mr. William Slezak | New York District |
| Dr. Dennis Smith | Waterways Experiment Station<br>Hydraulics Laboratory |
| Mr. George Strain | South Atlantic Division |
| Mr. John Sustar | San Francisco District |
| Mr. Burnell Thibodeaux | New Orleans District |
| Dr. Jim Whitley | Missouri Dept. of Conservation |
| Dr. Steve Weithman | Missouri Dept. of Conservation |

CONTENTS

THE COMMITTEE ON WATER QUALITY
BY
JANICE E. RASGUS[1]

The Committee on Water Quality has been in existence four years. It was formally established in December 1975. During the past year and a half, the Committee met 3 times. Several ER's and ETL's which provide guidance on various aspects of water quality management at water control projects have been completed by the Committee. These regulations are as follows:

1) ER 1110-1-261, Control of Field Testing Procedures, dated 28 September 1979. The purpose of this ER is to insure that reliable data are being generated for Corps water quality studies. It also assigns technical laboratory supervision to Division labs.

2) ER 15-2-10, Committee on Water Quality, dated 25 May 1979. This ER describes the objectives and responsibilities of the Committee and outlines its consulting services.

3) ER 1110-2-1402, Hydrologic Investigation Requirements for Water Quality Control, dated 15 September 1978. This regulation outlines specific hydrologic and water quality investigation requirements to be presented as part of the Survey Report and the Phase I and Phase II GDM's.

4) ETL 1110-2-244, Water and Wastewater Laboratory Quality Control, dated 14 May 1979. This ETL provides guidance on laboratory quality control procedures to be employed by Corps laboratories conducting water and wastewater analyses.

5) ETL 1110-2-239, Nitrogen Supersaturation, dated 15 September 1978. This ETL provides guidance for the evaluation and identification of those projects with hydraulic structures having the potential to produce nitrogen supersaturation.

6) ER 1110-1-8100. Laboratory Investigations and Materials Testing, dated 30 August 1974. This ER has been revised and will be released shortly. This regulation prescribes the responsibilities and procedures for laboratory investigations and materials testing services.

Much of the work of the Committee is done by four Work Groups. During CY 1979 the Work Groups were quite active and accomplished the following:

1) Work Group I drafted guidance on field measurements and laboratory analytical techniques to be used in detecting dissolved gases. An ETL containing this guidance will be released shortly.

[1]North Central Division, Vice-Chairman, Committee on Water Quality

2) Work Group II drafted an ETL on "Quality Control of Field Sampling for Evaluating the Physical and Chemical Characteristics of Surface Water and Sediment." This ETL will also be available soon.

3) Work Group III began formulating procedures which would establish water quality as a necessary item to be considered in the development of water control plans.

4) Work Group IV organized the "Water Quality Evaluation" seminar, evaluated water quality training needs and recommended training courses to meet these needs. One such course which will be offered 23-27 June 1980 at HEC is called "Water Quality Aspects of Water Control."

In addition to the Work Group activities, several members of the Committee participated in a consulting session with the Chicago District on the Chicagoland Underflow Plan. A series of questions and issues were raised by the District. The Committee responded to each one of these and made recommendations.

Members of the Committee should be contacted with any questions, concerns, suggestions or requests for consulting services. These will be brought to the attention of the Committee for discussion. The members of the Committee on Water Quality are:

Dr. Mark Anthony - ORD
Mr. Charles Bradshaw -LMVD
Mr. John Bushman - OCE
Mr. Richard DiBuono - NED
Mr. Harry Dotson - SPD
Mr. Earl Eiker - OCE
Dr. Rex Eley - WES
Mr. John Grace - WES
Mr. Howard Reese - MRD
Mr. David Legg - NPD
Mr. Thomas Maisano - NAD
Dr. Harlan McKim - CRREL
Mr. Jim Gottesman - OCE
Ms. Janice Rasgus - NCD
Mr. Julian Raynes - SAD
Mr. Charles Sullivan - SWD
Mr. Jerry Willey - HEC

RESERVOIR RELEASES
by
Earl E. Eiker [1/]

There has been an increasing national concern for protecting and preserving the environment. Review of past and present legislation reveals a trend that follows this growing concern. Initially, legislation was aimed at avoiding adverse impacts on the environment but provided neither true directives, nor procedures for enforcement. Words and phases such as "if possible," "practicable", and "reasonable," made legislation weak as far as initiating action. As interests and concerns increased, legislation became more action-provoking, and provided enforcement procedures. Legislation now requires environmental quality (EQ) to be a major consideration in resource development, and management activities. Because of its interrelationship with many aspects of EQ (Fish and wildlife, public health, water supply, recreation, etc.), water quality (WQ) in particular, has become a major environmental concern.

The first WQ efforts were directed toward public health and water supply (Water Pollution Control Act, 1948 PL 80-845). The Corps and other agencies developed policies, programs and studies to investigate and solve problems in this area. Knowledge gained through these studies provided a better understanding of pollution and stream sanitation, and broadened the focus on WQ concerns.

More recent environmental legislation, beginning with passage of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) and culminating with the Clean Water Act of 1977 (PL 95-217) has had a somewhat different thrust. Water quality improvement of all the nations waters has become the National goal. Of particular significance in PL 92-500, was section 313 which required Federal agencies to comply with the substantive requirements of state and local laws for pollution abatement. This legislation was reinforced by issuance of Executive Order 11752 which directed Federal agencies to provide leadership in the nationwide goal to protect and enhance the quality of our nations water resources. The Clean Water Act of 1977 (CWA) strengthened section 313 by requiring Federal agencies to meet both substantative <u>and</u> procedural requirements of state and local pollution abatement laws. Even more importantly, the CWA placed responsibility for meeting these requirements on heads of Federal agencies and provided procedures for citizen suits in cases of non-compliance. Once again these provisions were reinforced by issuance of an executive order, in this case EO 12088, Federal Compliance with Pollution Control Standards.

Recently, the movement to improve environmental quality received further executive support. On July 12, 1978 the President sent a directive to all Federal agencies involved in water resources development

1/ Hydrologic Engineering Section, Engineering Division, OCE

potential operation of the Richard B. Russell Dam, and the continued operation of Clark Hill and Hartwell Dams on the Savannah River, until the defendants complied with applicable Federal laws. The plaintiffs alleged that discharges from the dams will, or do, violate Section 301 of the FWPCA of 1972. According to Section 301 of the FWPCA, it is unlawful to discharge a pollutant into waters of the United States, unless certain permits are obtained - including a NPDES permit, as provided in Section 402 of the Act. They claim that the dams are, or will be, point sources of pollutants into the Savannah River, and that the discharges do not, or in the case of R.B. Russell will not, meet Georgia and South Carolina Water Quality Standards. In order for the Court to determine whether a 402 permit is required, a determination must be made as to whether the releases from a dam will involve "the discharge of any pollutant by any person..."

In February 1977, the Government filed a motion for dismissal. The basis for this motion was the Government's position that operation of these hydroprojects does not "add" pollutants from a point source, as required by Section 301 of the Act. The motion for dismissal was heard in South Carolina District Court in July 1978. The Court ruled that Clark Hill and Hartwell were dismissed from consideration in the suit due to the plaintiffs' failure to meet a procedural technicality. However, in regard to Russell, the Court found that, if it can be proven that impoundment results in the change of the chemical quality of the water, as the plaintiffs allege, then the discharge of this water will result in the addition of "pollutants" into the Savannah River as defined by section 502 (b) of the Act. Further, if the plaintiffs' description of the discharge pipes could be proven correct, the dam would be considered a point source because the discharge pipes could be defined as such under Section 502 (14) of the Act. Discharges that are made without a NPDES permit will thus be in violation of the CWA, and subject to appropriate sanctions. Because of these findings, the dismissal was denied. The suit is still awaiting hearing at this time.

In a related action, in February 1978, the National Wildlife Federation (NWF) petitioned EPA "to designate and set uniform effluent limitations for discharges from hydroelectric dams." The NWF viewed the dams as point sources of pollution, that should be regulated, under Section 402, of the FWPCA. They supported this view by fitting reservoir activities to the criteria for "point sources of pollution" as defined in Section 502(12), and (14) and (19) of the Act. No action was taken by EPA, and in 1979 the NWF took their case to court. At this time, the case is in the District of Columbia Court awaiting a hearing.

The outcome of these cases may have a significant impact on Corps water resources development projects. The Russell project probably will not be enjoined because plans to oxygenate the release waters have been

included in the design. However, existing projects may be subject to NPDES permits in the future, if the courts rule in favor of the environmental organizations, which seems very likely at this time.

In response to the President's memorandum on instream flows, an Interagency task force was formed under the chairmanship of the Department of Interior, to address the directives contained in the memorandum. A series of reports were produced by the Task Force including one which identified numerous Federal projects as having problems with quantity and/or quality of release water. Several Corps projects were included in this report. The Instream Flows report was submitted to the Secretary of the Department of Interior in May, 1979. Subsequently, Secretary Andrus requested that each agency provide additional information on the identified problem projects. This information was to include, in part, corrective actions being taken or proposed alternatives that may be selected, to remedy the identified instream flow problems. In response to Secretary Andrus's request, the Corps provided the above information. Information was collected from Division offices during September 1979, reduced to a composite form, and fowarded to the Assistant Secretary of the Army, CW, for his review and transmittal. Although Assistant Secretary Blumenfeld forwarded the information to Interior, he was not satisfied that it presented a complete picture of the problems, and ongoing corrective activities. He believed that the Corps is addressing instream flow problems more fully than described, and that these actions should be documented and incorporated into a systematic, Corps-wide approach. Accordingly, Secretary Blumenfeld requested that the Director of Civil Works prepare a plan of action to uniformly address instream flow problems.

Before such a plan can be developed, however, a comprehensive list of problem projects is needed in order to delineate the magnitude of reservoir releases problems. Individual problems can then be prioritized and addressed for resolution.

To achieve this, a Plan of Action (POA) was prepared in January 1980. This effort will be initiated with an Engineering Circular (EC) which will be sent to Division and District offices shortly. The EC will direct that a project by project evaluation be made, including estimated costs and specific authorities required to resolve problems. Divisions will be required to submit their responses in Part II of the Annual Division WQ reports (due 1 February 1981) pusuant to ER 1130-2-334. After Division reports are reviewed, and the required actions and costs determined, consideration will be given to putting a line item for instream flow programs in the budget. In this manner Congress will be advised of the magnitude of expenditures necessary to prevent and alleviate instream flow problems below Corps projects.

In summary, the described trend of legislation, the Presidents memorandum and ongoing litigation indicate a changing direction in the requirements on our activities. In the future we may be required to comply with State Water Quality Standards and to meet instream flow needs with reservoir releases at all our water control projects. Our policy therefore, must reflect this possibility. Division and District offices must work more closely with the States and EPA Regional offices to develop workable WQ Standards for reservoir releases and criteria with which to determine downstream flow requirements. If reservoirs are declared point sources of pollution, coordination will also be necessary to develope "Best Practical Treatment" guidelines. As a minimum we should press for consideration of factors such as ambient WQ conditions, existing and prospective water uses, fish and wildlife needs, public health, and economic impact during the development of these guidelines. Finally, whether we are ultimately required to meet instream flow needs at every project or not, our problems should still be clearly documented, the least costly alternative solution should be determined and the reasons for accepting or rejecting this alternative clearly defined. Only in this way will we be able to adequately coordinate our activities with the States and other Federal agencies and meet the intent of current legislation.

Section 404(b) Testing

By

Robert Pierce[1]

In October of 1978, I was asked to chair a working group of Corps personnel from across the country. Formation of this group resulted from the realization by OCE that the field was dissatisfied with the draft revision to the 404(b) Guidelines circulated shortly before by EPA. The group's responsibility was to review EPA's testing guidance and to develop a Corps proposal that was acceptable to both the field and OCE.

During the intervening period, the group has drafted a testing package, held workshops at which most Districts were represented, formally requested field comments and made numerous refinements to the proposal. EPA was continuously apprized of our progress and received copies of each iteration as it was developed. We have met with EPA on several occasions, discussed our testing package, answered questions and explained the rationale behind the various procedures.

I would like to describe to you the basic testing procedures that may be implemented in the not too distant future. Unfortunately, everything I say is tentative and is subject to changes made by EPA or the public following comment on the Guidelines. That which I will describe, however, is based on the discussions, modifications and agreements reached at our last meeting with EPA.

First, as a background, I would like to briefly discuss the basis for development of the Guidelines and then the testing procedures which are now in force, i.e., the 5 September 1975 Guidelines.

Section 404(b)(1) of the Clean Water Act of 1977 directs the Administrator of EPA in conjunction with the Secretary of the Army to develop guidelines governing the specification of sites for the discharge of dredged and fill material. These guidelines were to be based upon criteria comparable to criteria applicable to ocean discharge under Section 403(c).

Don't confuse this section with Sec. 103 of the Marine Protection, Research and Sanctuaries Act of 1972, which directed EPA to publish the Criteria under which ocean discharges now are regulated. The CWA was promulgated shortly before the MPRSA, and though superceded by Section 103 of the latter, Section 403 has been retained in the law and serves as a basis for the development of the Section 404(b) Guidelines.

[1]Biologist, Environmental Branch, North Atlantic Division

The criteria listed in Sec. 403 are as follows:

(A) the effect of disposal of pollutants on human health or welfare, including but not limited to plankton, fish, and shellfish, wildlife, shorelines, and beaches;

(B) the effect of disposal of pollutants on marine life including the transfer, concentration, and dispersal of pollutants or their by-products through biological, physical, and chemical processes; changes in marine ecosystem diversity, productivity, and stability; and species and community population changes;

(C) the effect of disposal, of pollutants on esthetic, recreation, and economic values;

(D) the persistence and permanence of the effects of disposal of pollutants;

(E) the effect of the disposal at varying rates, of particular volumes and concentrations of pollutants;

(F) other possible locations and methods of disposal or recycling of pollutants including land-based alternatives; and

(G) the effect on alternate uses of the oceans, such as mineral exploitation and scientific study.

It should be evident that the need to consider lethal effects, bioaccumulation, alternatives and mitigation is founded on the Law and not in the Guidelines themselves.

On September 5, 1975, EPA published its first set of guidelines in conformance with Section 404(b)(1). Although tests were described (some in more detail than others), selection of an appropriate test for any situation was essentially at the discretion of the District Engineer. Thus, the Guidelines stated that the District Engineer could use, specify or require:

1. Elutriate Tests;
2. Water Column Bioassays;
3. Benthic Bioassays;
4. Total Sediment Analysis (Bulk);
5. Biological Community Structure Studies; and/or
6. Biological Indicator Species.

In addition, the Guidelines indicated that EPA would publish a manual covering testing and sampling procedures, calculations and references. The manual has yet to be developed. In May 1976, WES, through the DMRP, published Interim Guidelines for implementing Sec. 404(b)(1). However, use of this report apparently never became widespread. The end result was that most of us never went beyond the use of elutriate and bulk sediment analyses and we prepared 404(b) evaluations that were less than thorough.

EPA and OCE evidently preceived a lack of commitment to the spirit of the Clean Water Act and decided that substantial revisions to the Section 404(b) Guidelines were in order. The initial Corps effort was at the Washington level, but was later transfered to the working group with active FOA participation. EPA headquarters, however, never has delegated the development of the testing portion of the Guidelines.

The working groups basic intent was to develop a testing package that would give a clear and unequivicable guidance on the appropriate test or tests needed to characterize the material to be discharged: which test to start with; under which situations additional tests are necessary; and when enough tests had been run. The underlying philosophy was to prescribe the minimum amount of testing necessary to protect the environment.

We wanted to take the onus of selecting the proper test away from the D.E., while leaving him with the flexibility to modify tests in a reasonable fashion as needed. At the same time we did not want him unnecessarily open to criticism for performing insufficient or incorrect tests. It was the belief of the committee that EPA's proposal was not sufficiently structured to provide these assurances.

In order to accomplish these goals we categorized discharges by the type of operation and the level of contamination in the dredged material and at the discharge site. The heart of this scheme is the precategorization evaluation. As the name implies it is the first step in the process and is the mechanism by which the discharge is placed into the proper category. In addition, during this evaluation, the contaminants of concern that may be present in the dredged material are identified.

"Contaminents of Concern" is the term which collectively refers to specific pollutants listed under Section 307(a) and other potentially toxic pollutants. The testing procedures do not cover such water quality problems as nutrient loading or coliform contamination. If such factors are potential problems, they also must be considered in making the factual determinations. They can generally be assessed independently of analyses for contaminants of concern.

During precategorization the permitting authority critically examined various factors to determine if there is reason to believe that any contaminants of concern may be present in toxic amounts or that there will be a degradation of water quality resulting from the discharge.

Factors to be considered in making this determination include:

(1) Identification of potential routes of specific contaminants of concern. This can be based on maps, aerial photographs, and other graphic methods that show watercourses, surface relief, proximity to tidal movement, private and public roads, location of buildings, agricultural land, municipal and industrial sewage and storm outfalls, etc;

(2) Pertinent results from previous tests on the material at the extraction site or on samples from other similar projects in the vicinity, when there are similarities of sources and types of contaminants, water circulation and stratification, accumulation of sediments, general sediment characteristics, and potential impact of the aquatic environment, as long as no known changes have occurred to render the comparisons inappropriate;

(3) The probability of past substantial introductions of contaminants from land runoff (e.g., pesticides);

(4) Records on spills of toxic substances or substances designated as hazardous under Section 311 of the Clean Water Act (see 40 CFR 116-119).

(5) Records indicating substantial introduction of pollutants from industries;

(6) Pertinent and applicable research results and monitoring programs;

(7) Natural deposits of contaminants of concern; and

(8) Source and previous use of materials proposed for discharge as fill.

I cannot overemphasize the importance of the precategorization evaluation. Not only is it the determining factor for the level of testing (and therefore the cost) required for each project, but to a great extent it will establish the credibility of the permitting authority in its overall duty to implement the Clean Water Act.

Briefly, the five categories for dredged material are:

1. Discharge without potential for Environmental contamination;

2. Open water discharge with level of contamination similar to the discharge site;

3. Contained or confined discharges;

4. Open water discharges with potential for harm to the benthic environment; and

5. Discharges with potential for harm in the water column.
Categories 1 to 4 can be entered directly, Category 5 would be entered only from another Category.

I will discuss these Categories in more detail later, but first, let me give you an example of the precategorization process. This diagram (Figure 1 ) depicts a "typical" coastal riverine and estuarine system. Two rivers merge to form a large embayment that discharges into the ocean. The cross-hatched areas represent cities. Located at various points are eight dredging operations, five open water (D) and one upland (U) discharge sites. The arrows represent the direction of the currents (it is tidal through a portion of the reach).

The smaller upstream city has industries which discharge contaminants of concern, A and B. These were identified through the EPA 402 files. The large, more industrialized city discharges CoC, C,E,F and G. Based on aerial photographs, maps, current patterns and other sources of information, we have determined that the drainage basins above sites 1 and 5 are moderately forested, without heavy agricultural activity and have no industrial sites. Sites 1 and 5 are composed primarily of fine grain sediments. While the discharge site for 1 is fine grain, the discharge site for 5 has a course grain substrate. Since there is no reason to suspect the presence of CoC in toxic amounts, the projects would meet the requirements of Category 1 and not require testing. Proceeding directly to the factual determinations, we would evaluate the physical effects of the discharge. Site 1 is fine grain on fine grain and we expect recolonization of benthic species to occur rapidly. Site 5, however, is fine grain on course grain and more consideration would have to be given to the advisability of using this discharge site. Generally, like on like grain size is preferrable.

Sites 2,3 and 4 are all contaminanted by one or two CoC's. Site 2 with the disposal site adjacent is a prime candidate for Category 2 having no reason to believe that a difference in levels of CoC would exist between the dredging and discharge sites. Similarly, site 4 would be expected to be less contaminated than the disposal site, therefore, qualifying for Category 2. Site 3, however, while initally fitting into Category 2, may require additional tests under Category 4 and possibly 5 because site three may be more contaminated than the porposed discharge site.

Dredging sites 6 and 7 are both proposed to be discharged at D(7). The material at site 7 is removed from sources of CoC, is in a high energy area and therefore, falls into Category 1. Site 6, however, is suspected to be contaminated with CoC's, C,E,F and G. Knowing that site 6 will be more contaminated than D(7) we would proceed immediately with the tests prescribed in Category 4 and then 5.

We could also consider sites 7 and 8 for upland containment (U). Since site 7 falls into Category 1 for open water discharge, testing normally would not be required if we go upland. Since site 8 is contaminated we would proceed with the tests prescribed in Category

I hope now that you understand the general concepts of the precategorization evaluation. In the remaining time I would like to quickly discribe the tests involved in each Category. Keep in mind as I cover each procedure, that the decision to specify or not to specify a disposal site is never derived in any category. The tests simply provide the technical information needed to make the factual determinations. The decision to specify or not is based on the factual determination.

Category 1 deals strictly with materials removed from sources of contamination. These can be either course of fine grain materials. Although no testing is required, the direct physical effects of the discharged need to be considered in making the factual determinations.

Category 2 is appropriate when CoC's may be present, but the availability of the contaminants from the discharged material are believed to be not substantively greater than at the discharge site, and thus, will not result in increased harmful effects to the resident community other than the direct physical effects. The appropriate tests are chemical comparisons of the concentrations of the contaminants of concern extracted from the dredged material with extracts of sediments from the discharge site and with the receiving water (Figure 2).

The primary purpose is to compare the biologically available fraction of CoC's in the sediments. Secondarily, the release into the water column is determined to define the size of the mixing zone. If the tests prove the hypothesis that the concentration of CoC in the discharge is not substantively greater than at the discharge site and the mixing zone is acceptable then testing is completed and we can proceed to the factual determination. If it is substantially greater, then the tests in Category 4 must be applied. If the mixing zone is unacceptable then we propose that the tests in Category 5 would be applied. EPA disagrees with this position if the CoC has an applicable water quality standard. This debate, is too lengthy to continue at this point in time. We believe, however, that the number of instances when Category 5 would be entered from 2 is very limited.

The extraction process will be specified in an updatable appendix to the Guidelines. For many of the common CoC's is a water elutriate extraction would be applicable. For some of the more exotic substances, other solvents may be specified.

Category 3 is applicable to any contained or confined discharge, when the return is into 404 waters and the material does not fall into Category 1. Since there is no concern for benthic impacts, the tests in this category is designed to assess the impacts of the effluent on the water column. The test is a comparison of CoC's in the receiving water with either a standard or modified elutriate, determined by the retention time of the effluent (Figure 3).

Should evaluation of the test results indicate that concentrations of the CoC's in the elutriate are not substantively greater than in the receiving waters than testing is completed and the factual determinations can be made. If there is a substantively greater increase and there is sufficient information after calculation of the mixing zone to assess the impacts on the water column, then testing would continue in Category 5. Again, EPA disagrees with this approach if the CoC's are subject to water quality standards.

Category 4 would be appropriate when CoC's have been identified in amounts which have the potential for substantive environmental harm after deposition of the dredged material. Our concern is primarily for the benthic community. Both bioassay and bioaccumulation analyses are required.

The bioassay compares survival of appropriately sensitive organisms in sediments to be dredged with similar reference sediments from the discharge site and a control (Figure 4). A minimum of one benthic and one epibenthic species will be utilized.

Depending upon the historical precedence for discharging the sediments at the proposed discharge site, bioaccumulation will be assessed either in the field or in association with bioassay tests, using organisms with a demonstrated propensity for accumulating the CoC's identified in the precategorization evaluation.

If Category 4 is entered directly then Category 5 testing is acquired to assess water column impacts. If Category 4 is entered from Category 2 then water column bioassays may not be needed and some of the CoC's may be eliminated from bioaccumulation analyses.

Remember that decisions on specification of discharge sites are only made through the factual determinations. Thus, there is no pass/fail point per sec in this or any category. The tests provide the information necessary to complete the factual determinations.

The last Category, 5, is never entered directly from the precategorization evaluation. Since research to date identifies benthic effects as the major impacts associated with dredged material discharge, this Category should seldom be needed and be resorted to last.

The test protocol calls for a comparison of organism survival in the unfiltered elutriate with survival in an unfiltered composite sample from the water-column at the receiving site (Figure 5). A minimum of one vertebrate and one invertebrate appropriately sensitive species will be used. Should statistically significant decreases in survival in the elutriate be observed then the mixing zone will be calculated based on the 96-hour LC50 of the elutriate. No further testing is needed.

That in a nutshell is the testing procedure for dredged material. Discharges of fill are much less complicated to deal with. We have established two categories into which fill can be placed;

a. Discharges without potential for environmental harm (6); and

b. Discharges with potential for environmental harm (7).

The first category (6) covers materials that have been identified through the precaterorization evaluation to be derived from uncontaminated sources or the contaminated structure is designed to prevent leaching. No testing is required.

Category 7 is used when there is a potential for leaching of contaminants of concern. The test is a comparison of a water leachate of the fill material with appropriate existing standards or criteria. No dilution factor or mixing zone determination shall be considered. There are no other tests for fill material.

The general philosophy underlying the fill material is that the loss of aquatic habitat is a serious enough pertubation that contaminated fill should not be used unless completely contained so as to prevent leaching. Unless this proviso is met, other sources of uncontaminated fill must be found.

As I stated in the beginning of my presentation, this testing scheme is tentative. EPA appears to be amenable to the general procedures and format that we have developed. At this time the only consequential difference we appear to have deals with the applicability of water quality standards. However, even if EPA's position prevails, we do not believe that it will have a serious impact on implementation of this program.

I cannot even hazard a guess at the date when the new Guidelines will become effective, since the date for publishing the testing package in the Federal Register is unknown. We are pushing for a phasing in the requirements to provide time for the Districts to come on line. Since this entire testing package falls under the umbrella of the 1975 Guidelines, however, Districts have the perogative to begin implementing it now. I would hardily encourage you to think along these lines. Even if this testing package does not make the final cut, I believe that more testing requirements, including bioassays and bioaccumulation, are inevitable.

Figure 1

Typical coastal riverine system.

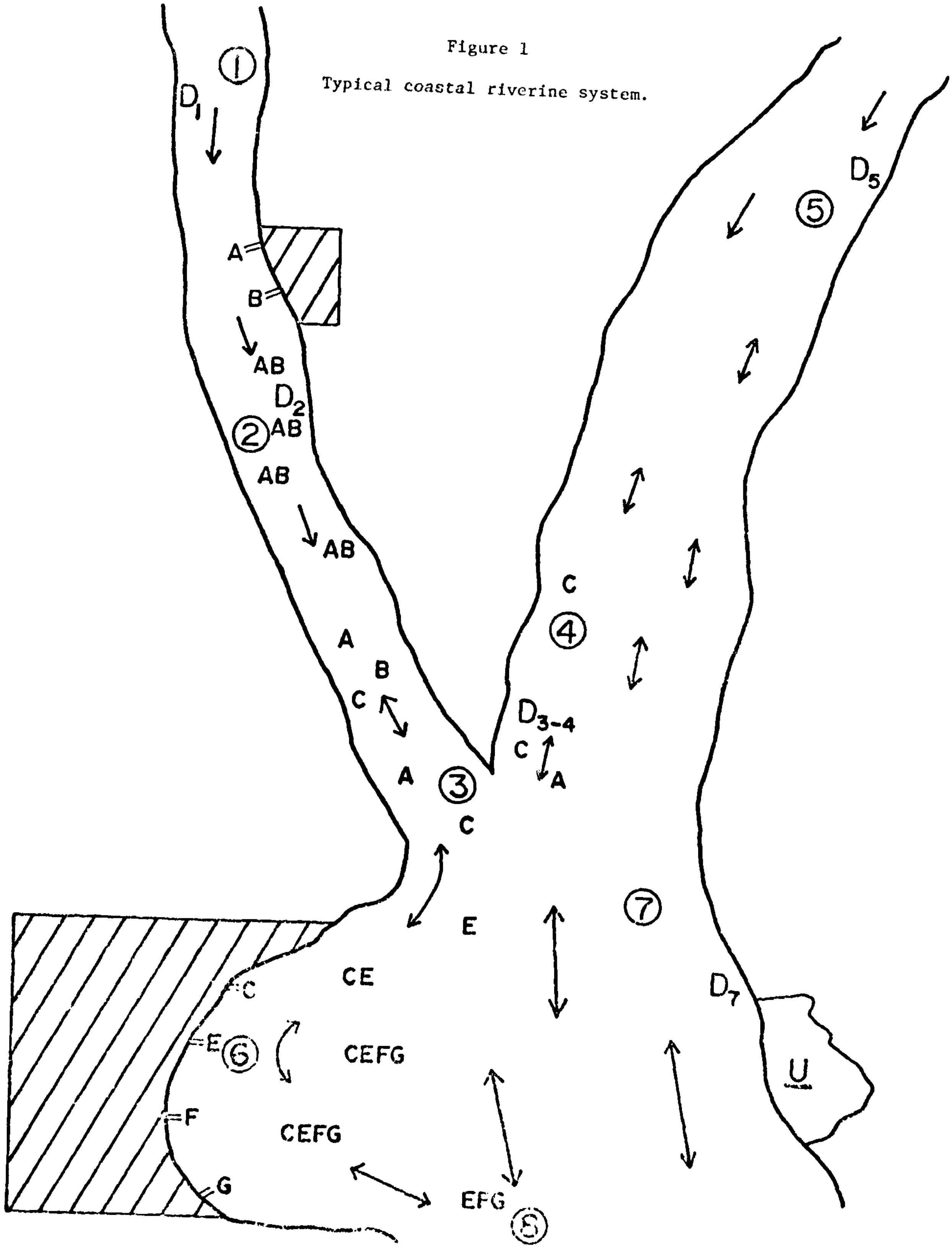
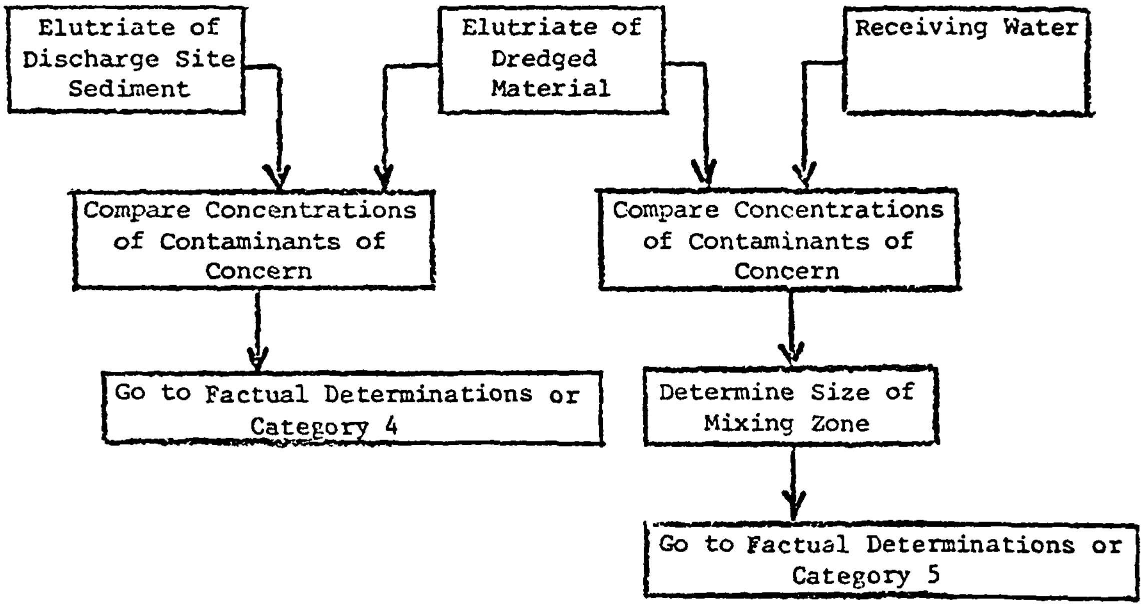


FIGURE 2

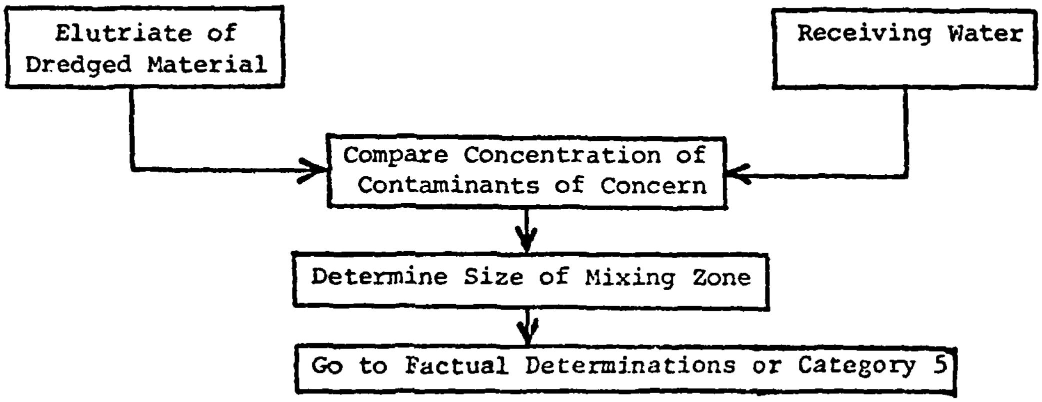
SCHEMATIC REPRESENTATION OF CATEGORY 2 TESTING




The concentrations of contaminants of concern in the elutriate of the material to be dredged are compared to concentrations in the elutriate of sediments at the discharge site to assess the potential for benthic impacts and the need to test further in Category 4. Concentrations in the dredged material elutriate are compared to concentrations in the composite receiving water and the size of the mixing is determined to assess the potential for impacts in the water-column and the need to test further in Category 5. Details are provided in 230.23(b).

FIGURE 3

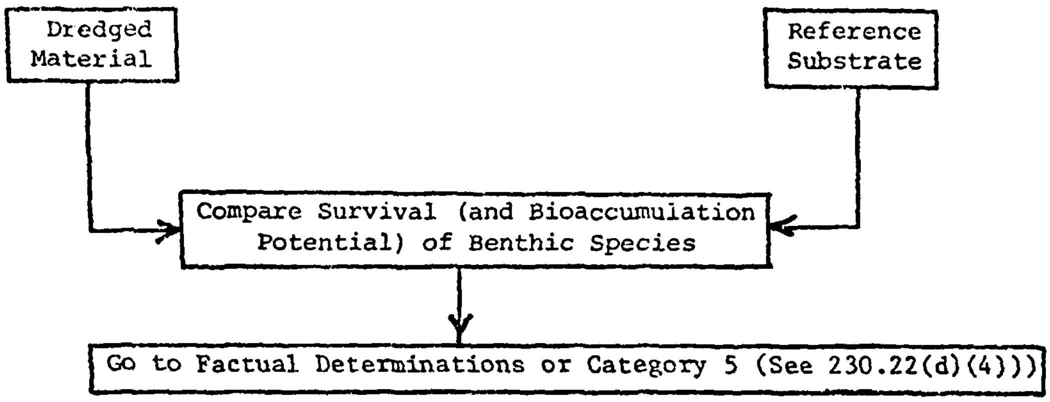
SCHEMATIC REPRESENTATION OF CATEGORY 3 TESTING




The concentrations of contaminants of concern in the elutriate or modified elutriate of the material to be dredged are compared to concentrations in the receiving water and the size of the mixing zone is determined to assess the potential for impacts and the need to test further in Category 5. Details are provided in 230.23(c).

FIGURE 4

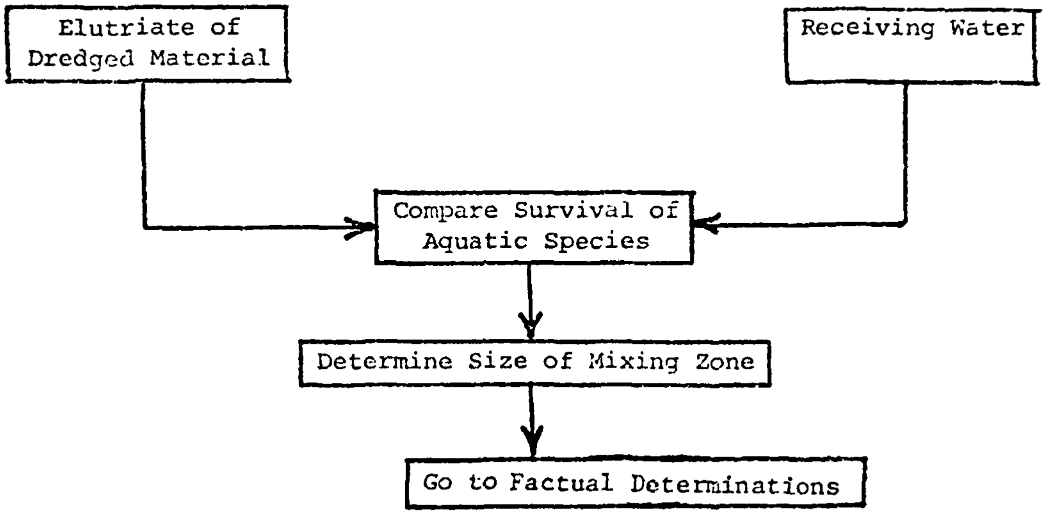
SCHEMATIC REPRESENTATION OF CATEGORY 4 TESTING




Survival (and bioaccumulation potential) of benthic and epibenthic species in the material to be dredged are compared to survival (and bioaccumulation potential) of the same species in the reference substrate to assess the potential for benthic impacts. Details are provided in 230.22(d).

FIGURE 5

SCHEMATIC REPRESENTATION OF CATEGORY 5 TESTING




Survival of aquatic species in the elutriate of the material to be dredged is compared to survival in the receiving water and the size of the mixing zone is determined to assess the potential for impacts in the water-column. Details are provided in 230.22(c).

STATUS OF THE ENVIRONMENTAL AND
WATER QUALITY OPERATIONAL STUDIES (EWQOS) PROGRAM

by

Jerome L. Mahloch[1]

## Introduction

The EWQOS Program was initiated in FY 78 and has completed 2 years of applied research on high priority environmental quality problems associated with Civil Works activities of the Corps of Engineers (CE). The major objective of the EWQOS Program is to develop new or improved technology to solve environmental quality problems while meeting project purposes. Products of the program will be applicable to all functional elements of the CE (i.e., planning, engineering, construction/operations). During the past 2 years, a majority of the effort associated with the program has been directed at literature reviews, planning and initial efforts associated with the long-term field studies, and preliminary or background laboratory studies to establish the direction of technology development and demonstration for the remainder of the program. In FY 80 and for the remainder of the program, products will be produced in a form directly usable by field offices, and a concentrated effort will be maintained on technology transfer activities to meet the program objective.

For purposes of discussing the status of EWQOS, notations used in organizing the program into coherent work packages will be employed. This organization is summarized in Table 1. Program hierarchy for this summary, Table 1, consists of projects and subordinate work units labeled as shown in the Table. Program status will be discussed by either project or work unit, as appropriate.

[1]Program Manager, EWQOS, Environmental Laboratory, USAE Waterways Experiment Station.

# TABLE I

EWQOS STATUS SUMMARY, FY 79

| Project Title/Work Unit/Task | Mode of Conduct* | Completion | Cost to Date | Status |
|---|---|---|---|---|
| I Predictive Techniques for Determining Environmental Effects | | | | |
| IA Reservoir Hydrodynamics | | | | |
| 1. Develop and verify techniques for describing inflow mixing processes | EL, HL; WES | Sep 80 | $ 96,000 | Active |
| 2. Develop and verify techniques for describing internal reservoir mixing processes | EL, WES | Sep 81 | 129,000 | Active |
| 3. Improve and verify physical hydrodynamic modeling techniques for reservoirs | HL, WES | Sep 83 | 151,000 | Active, interim guidance on use of physical models provided during FY 79 |
| 4. Improve and verify multidimensional hydrodynamic mathematical models | HL, WES; HEC: Contract, J. E. Edinger Asso., Inc. | Sep 83 | 167,000 | Active |
| 5. Develop and verify techniques for describing pumpback mixing processes | HL, WES | Sep 81 | 50,000 | Active, literature review and data evaluation being performed |
| 6. Modification of HEC-6 | HEC | Sep 78 | 25,000 | Complete, Users Manual published |
| 7. The behavior of fine sediments in reservoirs | HL, WES | Sep 82 | 60,000 | Active |
| 8. Forecasting the development of reservoir deltas | HL, WES | Sep 82 | 55,000 | Active |
| IB. Improved Description of Ecological and Water Quality Processes | | | | |
| 1. Improve and verify understanding and descriptions for reservoir ecological processes | EL, WES FWS-National Reservoir Research Progam USEPA; Las Vegas | Sep 83 | 238,000 | Active, fisheries algorithms complete, literature review for benthic, zooplankton, and phytoplankton ongoing |
| 2. Develop and verify description for *aerobic/anaerobic chemical processes* | EL, WES | Sep 83 | 338,000 | Active |
| 3. Develop and evaluate improved descriptions for important ecological processes unique to rivers | EL, WES | Sep 83 | -- | Initiate in FY 80 |
| 4. Formation and breakup of reservoir ice cover and effects on thermal energy budget computations | CRREL | Sep 83 | 132,000 | Active |
| IC. Mathematical Water Quality and Ecological Predictive Techniques | | | | |
| 1. *Improve and verify* existing one-dimensional reservoir water quality and ecological prediction techniques | EL, WES | Sep 83 | 315,000 | Active, revised model documentation completed in FY 79 |
| 2. Develop and evaluate multidimensional reservoir water quality and ecological predictive techniques | EL, WES | Sep 83 | -- | Initiate in FY 80 |
| 3. Improve and verify riverine water quality and ecological predictive techniques | EL, WES | Sep 83 | -- | Initiate in FY 80 |
| 4. Field test of the WQRRS river water quality module | HEC | Sep 80 | 95,000 | Active |
| ID. Determination of Loadings to Reservoirs | | | | |
| 1. Evaluation of existing techniques for predicting annual loadings to reservoirs | EL, WES | Sep 79 | 26,000 | Complete, final report to be published in FY 80 |
| IE. Simplified Techniques for Predicting Reservoir Water Quality and Eutrophication Potential | EL, WES | Sep 83 | 66,000 | Active, Phase I data base compilation completed |
| II. Reservoir Operational and Management Techniques | | | | |
| IIA. Management of Nuisance Algal Blooms in Reservoirs | | | | |
| 1. Define and evaluate major causes of nuisance algal blooms in CE reservoirs | EL, WES | Sep 79 | 100,000 | Complete, results to be published in FY 80, input to IIA.2 |
| 2. Develop and evaluate reservoir operational and management methods for controlling algal blooms | EL, WES | Sep 83 | -- | Initiate in FY 80 |
| 3. Evaluation of plant-mediated phosphorus release from sediments and effects on algal growth | EL, WES | Sep 80 | 145,000 | First phase experiments completed |
| IIB. Guidelines for Determining Releases to Meet Environmental Quality Objectives | | | | |
| 1-4. Guidelines for determining reservoir releases to meet environmental quality objectives | EL, WES; FWS-National Reservoir Research Program: Contract, Dr. James Duke, Consultant | Sep 83 | 535,000 | Active, sites selected, data collection ongoing to establish baseline conditions |
| IIC. Operational and Management Strategies for Reservoir Contaminants | | | | |
| 1. Survey of the nature and magnitude of reservoir contaminant problems | EL, WES | Sep 79 | 20,000 | Complete, input to IIC.2 |
| 2. Fate and effects of major chemical contaminants in reservoirs | EL, WES | Sep 80 | 30,000 | Active |

(Continued)

* Abbreviations used in this column are defined as follows:

EL - Environmental Laboratory
HL - Hydraulics Laboratory
WES - Waterways Experiment Station
HEC - Hydraulics Engineering Center
FWS - Fish and Wildlife Service
USEPA - U. S. Environmental Protection Agency
CRREL - Cold Regions Research and Engineering Laboratory
USAE - U. S. Army Engineer
LSU - Louisiana State University

EWQOS STATUS SUMMARY, FY 79 (Concluded)

| Project Title/Work Unit/Task | Mode of Conduct | Completion | Cost to Date | Status |
|---|---|---|---|---|
| IID. Reservoir Regulation Techniques for Water Quality Management | | | | |
| 1. Reservoir regulation constraints for water quality management | EL, WES | Sep 78 | $ 68,000 | Complete, internal working document, input to IID.2 and IID.3 |
| 2. Reservoir regulation techniques for water quality management | HL, WES | Sep 81 | 87,000 | Active |
| 3. Reservoir system regulation for water quality control | HEC | Sep 83 | 60,000 | Active |
| IIE. Environmental Effects of Fluctuating Reservoir Water Levels | | | | |
| 1. Vegetation for reducing effects of fluctuating pool levels | EL, WES | Sep 83 | 389,000 | Site selected and planted, literature review complete, flood trials initiated |
| IIF. Reservoir Site Preparation | | | | |
| 1. Develop procedures for reservoir site preparation and filling | EL, WES | Sep 83 | 25,000 | Active |
| III. Engineering Techniques for Meeting Reservoir Water Quality Objectives | | | | |
| IIIA. Techniques to Meet Environmental Quality Objectives for Reservoir Releases | | | | |
| 1. Evaluate field reaeration data at existing structures | HL, WES | Sep 82 | 165,000 | Active, report being reviewed |
| 2. Develop techniques to determine the reaeration potential of structural modifications | HL, WES | Sep 81 | 141,000 | Active, Miscellaneous Paper - Gas Tracer Measurements of Reaeration; Application to Hydraulic Models |
| 4. Describe the selective withdrawal characteristics of various outlet configurations | HL, WES | Sep 82 | 280,000 | Active, revised design guidance available |
| IIIB. In-Reservoir Techniques for Improvement of Environmental Quality | | | | |
| 1. Evaluate the effectiveness of reservoir mixing/destratification techniques | HL, WES | Sep 81 | 150,000 | Active, first phase evaluation published (TR E-79-1) |
| 2. Environmental effects associated with reservoir mixing/destratification aeration/oxygenation techniques | EL, WES | Sep 82 | -- | Initiate in FY 80 |
| 4. Evaluate the effectiveness of reservoir aeration/oxygenation techniques | HL, WES | Sep 83 | 110,000 | Active |
| IV. Environmental Assessment Techniques for Project Planning and Operationl Requirements | | | | |
| IVA. Alternative Techniques for Environmental Analysis | EL, WES | Sep 83 | 486,000 | Active, EC published, review of applicable methods being conducted |
| IVB. Data Management and Indices for Environmental Assessment | | | | |
| 1. Review and evaluate data management techniques applicable to environmental assessment | EL, WES | Sep 80 | 49,000 | Complete, survey report to be published in FY 80 |
| 2. Evaluate selected biological indices that have potential application to impact assessment | EL, WES | Sep 83 | 90,000 | Active |
| V. Environmental Impacts of Waterway Activities | | | | |
| VA. Environmental Impact of Selected Channel Alignment and Bank Revetment Alternatives on Waterways | EL, WES | Sep 83 | 145,000 | Active |
| VB. Impacts of Navigation Activities on Waterways | EL, WES | Sep 33 | 115,000 | Active |
| VI. Waterway Project Design and Operation for Meeting Environmental Objectives | | | | |
| VIA. Operational Procedures for Waterway Projects to Attain Environmental Quality Objectives | | | | |
| 1. Identify, document, and evaluate the effects of waterway operational procedures on environmental quality | EL, WES | Sep 80 | 60,000 | Survey complete |
| VIB. Design and Construction Techniques for Waterway Projects to Attain Environmental Water Quality Objectives | | | | |
| 1. Identify, evaluate, document factors in design and construction of waterway projects affecting environmental objectives | EL, WES | Sep 80 | 95,000 | Survey completed |
| VII. Long-Term Comprehensive Field Studies | | | | |
| VIIA. Reservoir Field Studies; Field Studies for Environmental and Water Quality Aspects of Reservoirs<br>1. DeGray Reservoir<br>2. Red Rock Reservoir<br>3. Eau Galle<br>4. West Point Reservoir | EL, WES: USAE District, Rock Island; Arkansas Water Resources Research Center | Sep 83 | 1,500,000 | Final selection complete, pilot surveys and initial data base complete, full-scale data collection under way |
| VIIB. Waterway Field Studies; Long-Term Field Studies Associated with the Environmental Quality of Waterway Projects<br>1. Tennessee-Tombigbee<br>2. Mississippi River | EL, WES; Contract, FWS Co-op Unit at LSU | Sep 83 | 1,440,000 | Final selection complete, pilot surveys and initial data base complete, full-scale data collection under way |

## Program Status

Accomplishments related to reservoir hydrodynamics (IA) include work on describing reservoir inflow and internal mixing, physical modeling of stratified reservoirs, the effects of scale distortion in physical models, and evaluation of two-dimensional hydrodynamic models which resulted in selection of one model for further development. Work related to reservoir biological and chemical processes (IB) that has been completed includes a literature review on phytoplankton, zooplankton, and benthos dynamics, laboratory studies of anaerobic processes, initial coding and testing of an anaerobic algorithm for reservoirs, and work related to the effects of ice cover and thermal energy exchange across the sediment-water interface. Accomplishments in modeling (IC) include the incorporation of subroutines for variable layers, suspended solids, and fisheries within the one-dimensional reservoir model plus development of a user manual, including guidance on data preparation, coefficient selection, and output interpretation. Monte Carlo methods developed for the one-dimensional model have been applied in several specific project studies. A compilation of existing data sets and available methods for predicting annual loadings to reservoirs has been completed (ID) and work (IE) was initiated on the compilation and evaluation of data sets from reservoirs for the development of simplified techniques, such as coliform transport. Currently, water quality and associated physical data have been compiled and summarized for over 300 CE reservoir projects.

Many of the work units within Project I represent efforts that will continue during FY 80. Emphasis will be placed on the hydrodynamics of pumpback mixing, improvement of two-dimensional hydrodynamic models, and development of techniques for the transport of suspended solids in reservoirs (IA). Within the remaining work units on modeling (IB and IC), work will be initiated on chemical processes related to partitioning of constituents between the soluble and particulate phases, initial evaluation of critical ecological processes in rivers, development of multidimensional water quality and ecological models for reservoirs, and an evaluation of selected riverine models. Work will continue on the development of simplified techniques, such as nutrient loading models, based on the assembled data base.

Accomplishments in Project II include an evaluation of control methods for nuisance algae (including state programs), which is currently being published, and completion of work on internal cycling of nutrients by aquatic plants (IIA). Field studies (IIB) to develop release criteria for both flood control and hydropower projects were performed and the effort coordinated with methods developed by the U. S. Fish and Wildlife Service Instream Flow Group for determining minimum stream flow requirements. Field studies (IID) of the use of vegetation to control impacts of fluctuating reservoir pool elevations have been initiated. A literature review on this work unit has been completed and published in addition to initial guidance on vegetation to be used. Reservoir regulation work (IID) has developed management techniques to meet water quality objectives; work on regulation for temperature objective is complete.

Work in FY 80 will include selection of nuisance algae control methods for demonstration and field evaluation (IIA), continued field studies at release sites and completion of a literature review and summary of reservoir tailwater habitat requirements (IIB), and reservoirs with vegetation trials (IIE). Contractor evaluation of major containment problems at reservoirs (IIC) will be completed, work on reservoir fisheries management will be initiated, and laboratory studies related to reservoir site preparation will be intensified.

Accomplishments in Project III include the field evaluation of reaeration for nonhydropower projects, initiation of work to determine the reaeration potential of structural modifications, and improvement in the capability to describe selective withdrawal under varying designs, plus updated design guidance and input to a revised outlet works manual (EM 1110-2-1602). Work related to improvement of in-reservoir water quality involved evaluation of mixing/destratification techniques and aeration techniques. Initial guidance on reservoir destratification has been published. Results of work within Project III have been applied to several projects. During FY 80, work will continue on evaluation of various outlet works, selective withdrawal design, reservoir destratification/mixing, and work on the ecological effects of reservoir destratification/aeration will be initiated.

Accomplishments in Project IV include review documents for critical variables in the four accounts under Pinciples and Standards and environmental assessment methodologies, a legal review of quantitative approaches to environmental assessment, elevation of current environmental data management practices in the CE, plus initiation of a compilation of biological indicators and environmental indices for riverine systems. Two EC's have been published to obtain field input on work related to environmental assessment. Work in FY 80 will concentrate on completion of an evaluation of environmental analysis techniques applicable to the ER 1105-2-200 series planning regulation and evaluation of the feasibility of the use of biological indicators or indices for riverine projects.

Accomplishments in Project V include completion of a short-term field study of Section 32 demonstration projects (Omaha District) and a literature review of the environmental effects of waterways projects that will be completed during FY 80. The development of techniques to evaluate environmental impacts of principal waterway activities will continue into FY 80, concentrating on habitat evaluation procedures. Short-term field study sites will be surveyed and selected to complement and extend the applicability of results for the long-term studies (VIIB).

Accomplishments in Project VI include completion of an evaluation of current design and operations technology for waterway projects from available literature, CE Division and District offices, and other Federal agencies. Guidance has been developed on environmental considerations for channelization projects. As results are synthesized from Project V and Work Unit VIIB, guidance will be developed for improved design and operation of selected waterway projects.

Accomplishments in the Reservoir Field Studies (VIIA) include selection of four study sites: DeGray (Vicksburg District), Red Rock (Rock Island District), Eau Galle (St. Paul District), and West Point (Mobile District). Following site selection, available data on all projects were compiled and analyzed. Field studies have been initiated at all field study sites under varying operational and seasonal conditions. Detailed studies were concluded at DeGray and Red Rock sites to provide input to other work within the program. Detailed analysis of sampling requirements to define environmental quality at these sites has been conducted. Field studies will be continued at all reservoir sites throughout the program. Work within the Reservoir Field Studies includes design of sampling programs, exchanges between reservoir compartments (e.g. embayments), within compartment dynamics, and general response of a reservoir to varying project conditions. Work within the Reservoir Field Studies may be characterized by routine monitoring plus intensive studies designed to answer specific questions and are designed to provide input to EWQOS Projects I-III. Additionally, information attained from the Reservoir Field Studies is expected to provide guidance to Division and District offices on sampling, testing, and analysis of environmental data from reservoir projects.

Accomplishments in the Waterways Field Studies (VIIB) include selection of two primary study sites: the lower Mississippi River (river miles 480-530, Vicksburg District) and the Tennessee-Tombigbee Waterway (Mobile District). Extensive field studies have been conducted at both sites. For both sites, especially the Tennessee-Tombigbee, extensive coordination activities were conducted to determine specific study areas within the project to complement ongoing studies by the District. For the lower Mississippi River study site, specific attention is being directed at the environmental effects of dikes and revetments. Work will define the various aquatic habitats within the study reach, quantify the effect of CE activities on the study sites (including before and after comparisons), and develop techniques for obtaining data specifically related to environmental impacts of dikes and revetments. Activities within the Tennessee-Tombigbee study site will produce data on the effects of navigation channelization (bendway cutoffs) on water quality, sediment transport, fisheries, and benthic communities. Comparable bendway cutoffs will be studied to determine the effects of location as well as an experimental structure to control the sedimentation within a cutoff bendway. Sampling, testing, and analytical guidance will be provided to Division and District offices as an end-product from the Waterway Field Studies. Results of these studies will be employed to develop improved design or operation guidance for waterway projects, and provide input to Projects V and VI.

Work within Project VIII has concentrated on coordination activities and is responsible for overall Program Management. Coordination activities have included 13 Federal Agencies or Departments, and 25 State environmental agencies, plus numerous regional and local groups. Intensive coordination and assistance activities with the U. S. Fish and Wildlife Service, specifically the In-stream Flow Needs Group and Habitat Evaluation Project have been conducted under Work Unit VIIIB.

## Summary

EWQOS is directed at solving high priority environmental quality problems affecting the CE and has been designed and conducted to responsive to field office requirements including extensive technology transfer activities. Tangible benefits expected are reduced time and resource requirements to solve environmental quality problems (i.e. directly affecting projects schedules) plus documentation of environmental benefits accrued by technology developed under EWQOS.

# SYSTEMATIC DESIGN OF INLAND WATER QUALITY NETWORKS: STRATEGIES FOR THE CORPS OF ENGINEERS

By

Michael Koryak[1]

## INTRODUCTION

Within a broad perspective of economic and institutional constraints and historical water quality conditions, the design of water quality monitoring networks has traditionally been a subjective process. Decisions as to the number of stations in a network, station locations, sampling frequencies and parameter coverage are based primarily on the intuitions and judgment of the individual designers.

In recent years a widespread interest has developed on the subject of more rational criteria for the systematic design of water quality monitoring networks. Probably the most prolific authors on this topic are a Colorado State University centered group. The following reference represents a current comprehensive coverage of the subject, and is recommended for anyone wishing to examine the available techniques in more detail:

Sanders, T.G., Ward, R.C., Loftis, J.C. and Steele, T.D., 1979. Design of Water Quality Monitoring Networks. Colorado State University, Fort Collins, Colorado.

The techniques and concepts they discuss are for the most part intended for application in the design of fixed-station, long-term monitoring networks of inland riverine systems. At several points this discussion will focus on techniques from Sanders _et al_, 1979, which appear to be applicable to the specific monitoring needs of the Corps of Engineers.

## MONITORING OBJECTIVES

Before designing a system, it is essential to attempt to define the desired objectives; that is the way that the data will eventually be utilized. This initial step of network design is probably the most subjective and potentially controversial part of the process. Admittedly, while surveys can serve multiple purposes, I personally conceptionalize two basic categories of water quality monitoring objectives which require correspondingly different strategies. These

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two categories of objectives and appropriate survey strategies are summarized below:

| Purpose | Survey Strategy |
|---|---|
| 1. Water Quality Characterization and Trend Identification | Routine |
| 2. Deterministic Water Quality Investigations | Synoptic<br>Scheduled:<br>riverine<br>limnologic<br>effluent<br>Unscheduled:<br>riverine<br>limnologic<br>effluent |

Routine monitoring to characterize water quality conditions and trends is normally accomplished by long-term, fixed-time increment sampling at permanent station locations. Such surveys are also usually routine in the sense that they have no date at which they are designed to terminate. They are usually riverine and this type of survey allows for effective application of standard statistical analyses.

A pervasive emphasis on routine monitoring evolved as a result of the Water Quality Control Act of 1965 (P.L. 89-234). Implementation of P.L. 89-234 resulted in both the establishment of stream standards as the basis of water quality management, and the creation or reorientation of federal, state and local agencies across the United States.

Passage of the Federal Water Pollution Control Act Amendment of 1972 (P.L. 92-500) shifted emphasis in regulatory water quality management from strictly stream standards to a combined stream and effluent standard basis. Therefore, most agencies began to more frequently complement routine surveys with synoptic surveys. With enforcement-oriented agencies this primarily involved effluent and receiving water monitoring. Such effluent surveys can be scheduled when dealing with chronic pollution, or unscheduled as during unique pollution events. They will normally be short term or have a designated termination date.

The term effluent is used here in the traditional sense and is not intended to include the outflow of Corps dams. Limnologic surveys are here defined as those which include a vertical dimension, and I have lumped short-term basic reconnaissance into the synoptic strategy category.

The Corps of Engineers has rather limited enforcement authority and, therefore, has limited justification for looking up peoples pipes with scheduled effluent surveys. Nor do we have a clearly defined mission to simply characterize water quality conditions and establish trends as does the U.S.G.S., state environmental resource agencies and some river basin commissions. Therefore, except when a Corps project is directly involved, or when other agencies efforts

are not adequate for Corps needs, scheduled effluent and high frequency routine sampling by the Corps could duplicate the efforts and usurp the authorized responsibilities of other agencies.

By process of elimination the Corps of Engineers monitoring activities should probably emphasize riverine and limnologic synoptic surveys, and with my personal conception of the agencies mission, these surveys should be hydrologically and operationally oriented.

In the Pittsburgh District, the monitoring approach is towards intensive but short-term specific flow and operation surveys. Of 870 established Corps of Engineers stations in the District, only 30 could clearly be considered as routine. Seventeen of these are year-round, semi-monthly analyses of existing and proposed reservoir outflows, and nine are year-round, semi-monthly reservoir inflow stations. The purpose of these 26 stations is basically water quality characterization and trend identification. The other 4 remaining stations fall into a multipurpose category. These are 24-hr./day remote sensing stations. They are utilized for trend identification and for the day-to-day water quality operation of a system of reservoirs. Without the latter synoptic element to their use, it is doubtful that the District could economically justify the high cost of these stations. The other 840 stations are all primarily synoptic riverine and limnologic.

In addition to Corps stations, we have a number of daily reporting stations that are sampled by municipal and industrial water users. The information from these sources is again used as criteria for day-to-day reservoir operations.

A monitoring system matrix, as shown in Figure 1, can be helpful in allocating resources and in establishing a monitoring strategy appropriate to specific purposes. To be truly representative, such a matrix can be expanded to include the entire process of monitoring activities from network design to sample collection, laboratory analysis, data handling, data analysis and eventual information utilization.

## LOCATION AND NUMBER OF STATIONS

Among the criteria that may be utilized to determine the locations and numbers of stations are: historical water quality data, water use priorities, fisheries, flow, political or jurisdictional boundaries, population density, industrial concentrations, agricultural or other land-use practices, or the location and area of influence of Corps projects.

The following procedure can be used to systematically subdivide river networks into portions which are relatively equally weighted in terms of any chosen criteria. The major criteria weighted centroid where a first hierarchy station is to be placed would be located in that link whose magnitude is closest to:

$$M_i = \frac{N + 1}{2}$$

where: $M$ = magnitude of link
$i$ = hierarchy level
$N$ = criteria value

Links are defined as the length of river between successive criteria reference points (i.e., outfalls, etc.).

If the first hierarchy link were erased, two systems result which are approximately equal in weighted magnitude. The upstream portion has a magnitude for which the centroid is:

$$M_{i+1} = \frac{M_i + 1}{2}$$

For the downstream portion the centroid may be found by selecting the link which is closest to:

$$M_i = \frac{M_d - M_u + 1}{2}$$

where: $M_d$ = magnitude where the basin is divided on the downstream side
$M_u$ = magnitude where the basin is divided on the upstream side
$M_i$ = alternate possible centroids

The following example of an application of Sharp's procedure was taken from Sanders <u>et al</u>, 1979, and is based on the number of outfalls which discharge into the Connecticut River and its tributaries. A map of this river showing the cumulative distribution of outfalls is shown in Figure 2. The major outfall centroid within Connecticut would be placed at:

$$M_i = \frac{151 + 1}{2} = 76$$

In this particular case, the outfall closest in magnitude to 76 was number 69 at mile 81 on the mainstem and a first hierarchy station was placed at this location (Figure 3). Note that the authors were oriented so as to automatically place a first hierarchy station at a political boundary, then for the upstream half, the second hierarchy station is located at:

$$M_2 = \frac{69 + 1}{2} = 35$$

and the upper third hierarchy is found at:

$$M_3 = \frac{35 + 1}{2} = 18$$

Turning to the lower half of the basin, the second hierarchy is selected from outfalls.

$$M_2 = \frac{151 - 69 + 1}{2} = 41$$

and

$$M_3 = \frac{41 + 1}{2} = 21$$

The same type of analysis can be done for any number of criteria besides outfalls. For instance, the cumulative BOD loading of the river is shown on Figure 4, and the station locations and hierarchy levels selected from the BOD criteria are shown on Figure 5. Note the close resemblance between the stations selected on the basis of outfalls with those selected on the basis of BOD loading.

The technique is very interesting and truly objective, but we've never used it and I don't believe that we ever will because it is entirely inadequate for our purposes. Note that the location of a dam (Holyoke Dam) is indicated in every plot. This dam was included in all the plots, but only for the purpose of illustrating techniques to determine microlocations for sampling stations. Microlocation determination was presented as an alternative to the convenience of bridge sampling. There will be no attempt here to present these microlocation techniques or expound on the problems of bridge sampling, as accessibility is considered to be an entirely ligitimate real world critieria in sampling station location selection.

But getting back to the point, the design and operation of a large mainstem dam on a river can influence the oxygen budget of the stream as much as tens or hundreds of outflows and cannot be ignored. If the project is Corps of Engineers', then inflow, outflow and probably pool stations become essential. To put a hydrologic slant to the monitoring system, major downstream tributaries would automatically be considered, as water quality varies along with the relative flow contributions of these tributaries to the mainstem. Also, the centroid procedure ignores the important concept of a control station.

Generally, I still believe that the traditional above and below major tributaries, industrial areas, municipalities and projects criteria will generate far more meaningful information than the centroid technique.

## SAMPLING FREQUENCY

Pomeroy and Orlob (cited in Sanders et al, 1979) have suggested that six equally-spaced samples per year are required to characterize stream water quality variables which have an annual cycle. These six samples per year could be used as a rough guideline for the minimum acceptable frequency for most routine sampling purposes.

Wastewater treatment plant and hydropower operations can induce both daily and weekly cycles. Diurnal variation in photosynthesis and respiration creates diurnal periodicities for dissolved oxygen, and sometimes pH, acidity, alkalinity and other parameters. Sanders et al, 1979, state that it is important to avoid taking all samples at the same point in a cycle in order to avoid biasing

the data. For example, a mean computed from samples taken at cycle-peaks could be much larger than the true mean. While this statement is certainly correct, the recommendation reflects a bias towards routine surveys. For a deterministic analysis, one different approach would be a reduction in stochastic level. That is, for instance, the computation of multiple means if necessary, such as seperate means for hydropower generation and non-generation periods.

Flow and drainage area are also functionally related to the variability of water quality, smaller watersheds usually demonstrating more rapid water quality change than larger ones. Again, Pomeroy and Orlob defined sampling frequencies as functions of drainage areas and the ratio of the maximum flow to the minimum flow.

Without citing quantitative data, it was recommended that watersheds with a drainage area greater than 1,000 square miles should be sampled at least 12 times a year, whereas a watershed which drains 10 square miles should be sampled 104 times a year. They also suggest that streams with high maximum flow to minimum flow ratios require more sampling than streams with low maximum flow to minimum flow ratios (Figure 6). A Corps of Engineers synoptic sampling program would perhaps most appropriately be designed to collect samples within specific flow ranges.

No matter what or how you are sampling however, water quality variation at some point becomes a stochastic process, where the law of diminishing economic returns per unit effort will eventually come into effect. For example, as shown in Figure 7, there is a rapidly diminishing expected confidence interval width for random sampling frequencies in excess of 20 per year for the eight different stations on the Green River. Unless some deterministic (synoptic) sampling strategy is introduced, more than 20 samples per year at any of these stations might, therefore, be statistically and economically difficult to justify.

## PARAMETER COVERAGE

Parameter selection is perhaps more difficult to generalize upon than any other aspect of monitoring network design. Usually the choices that must be made are self evident or site specific. Several crude generalizations appropriate for Corps of Engineers monitoring systems are that water temperature and dissolved gas concentrations (particularly oxygen, carbon dioxide and nitrogen) are highly sensitive to water resource engineering manipulations. Channel modifications and impoundment can effect these parameters directly or indirectly, and induce a wide range of secondary quality effects.

Besides such cause-effect relationships, another important point to consider is that many or most chemicals in aqueous solution tend to occur in various aggregated groups. This tendency makes it possible to facilitate water quality reconnaissance and to refine sampling schedules by utilizing different indicator parameters. For example, in the Upper Ohio River drainage basin we utilize specific conductance as an indicator of a wide range of acid mine drainage related parameters including iron, manganese, trace heavy metals, acidity, sulfates, TDS, hardness, etc. When elevated values of this conservative and

easily measured parameter are detected in the field, then more extensive parameter coverage of the affected area, upstream reconnaissance, or closer depth increment sampling in a reservoir can be justified.

This type of indicator is particularly useful in limnologic surveys. The Pittsburgh District, for instance, routinely takes vertical profiles of water temperature, dissolved oxygen and conductance at its reservoir projects with cabled probes. The number, degree and depth of discontinuties in the water temperature, dissolved oxygen, and conductance vertical profiles is then used as a partial criteria for the number and depth of the more expensive and time consuming metals, nutrients and biological samples to be collected.

Biological samples also serve as very useful indicators. While the number of chemical and physical parameters that can realistically be monitored is very limited, the number of potentially harmful contaminates and circumstances is extensive. Also the chemical samples only reflect conditions for the short-term periods when the samples are actually collected. Aquatic organisms on the other hand tend to integrate all of the stresses placed on the aquatic system and reflect combined effects over extended time periods. Benthic macroinvertebrates are particularly suitable as indicators because of their relative immobility and frequently long-life cycles. I realize the tremendous problems that sometimes occur with interpretation of results. In addition, there is a wide range of sampling and identification procedures in use that detracts from intercomparison of the results of different researchers. However, these samples still remain as value verification of chemical monitoring results and can indicate inadequacies in the chemical-physical data interpretations.

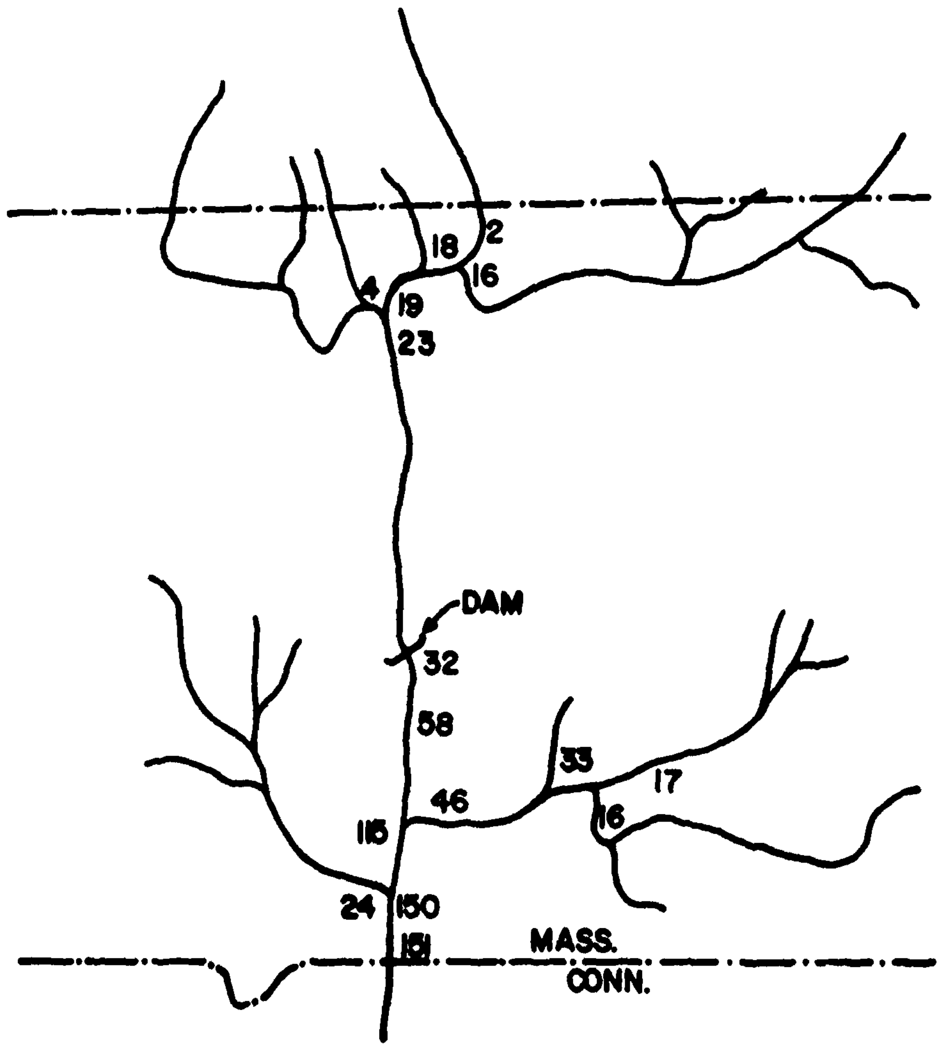
## SUMMARY

Probably the most definitive conclusion that could be made is that there are relatively few firm guidelines available for the systematic design of water quality monitoring networks. Flexibility and good judgment are essential and the process will probably always remain largely subjective and site specific. However, I don't believe that there are many networks planned or presently in existence that could not profit from a close examination of institutional goals, and the appropriateness of station locations, sampling frequencies and parameter coverage.

| MONITORING PURPOSES / MONITORING ACTIVITIES | CHARACTERIZATION AND TREND I.D. | DETERMINISTIC | | | | | |
|---|---|---|---|---|---|---|---|
| | | SYNOPTIC | | | | | |
| | | SCHEDULED | | | UNSCHEDULED | | |
| | ROUTINE | RIV | LIM | EFF | RIV | LIM | EFF |
| **NETWORK DESIGN**<br>1. STATION LOCATION<br>2. PARAMETER SELECTION<br>3. SAMPLING FREQUENCY | | | | | | | |
| **SAMPLE COLLECTION**<br>1. SAMPLING POINT<br>2. FIELD MEASUREMENTS<br>3. SAMPLING TECHNIQUE<br>4. SAMPLING PRESERVATION<br>5. SAMPLE TRANSPORT | | | | | | | |
| **LABORATORY ANALYSIS**<br>1. ANALYSIS TECHNIQUES<br>2. OPERATIONAL PROCEEDURES<br>3. QUALITY CONTROL<br>4. DATA RECORDING | | | | | | | |
| **DATA HANDLING**<br>1. DATA RECEPTION<br>A. LABORATORY<br>B. OUTSIDE SOURCES<br>2. SCREENING AND VERIFICATION<br>3. STORAGE AND RETRIEVAL<br>4. REPORTING<br>5. DISSEMINATION | | | | | | | |
| **DATA ANALYSIS**<br>1. BASIC SUMMARY STATISTICS<br>2. REGRESSION ANALYSIS<br>3. WATER QUALITY INDICES<br>4. QUALITY CONTROL INTERPRET<br>5. TIME SERIES ANALYSIS<br>6. WATER QUALITY MODELS | | | | | | | |
| **INFORMATION UTILIZATION**<br>1. INFORMATION NEEDS<br>2. REPORTING FORMATS<br>3. OPERATIONAL PROCEEDURES<br>4. UTILIZATION EVALUATION | | | | | | | |

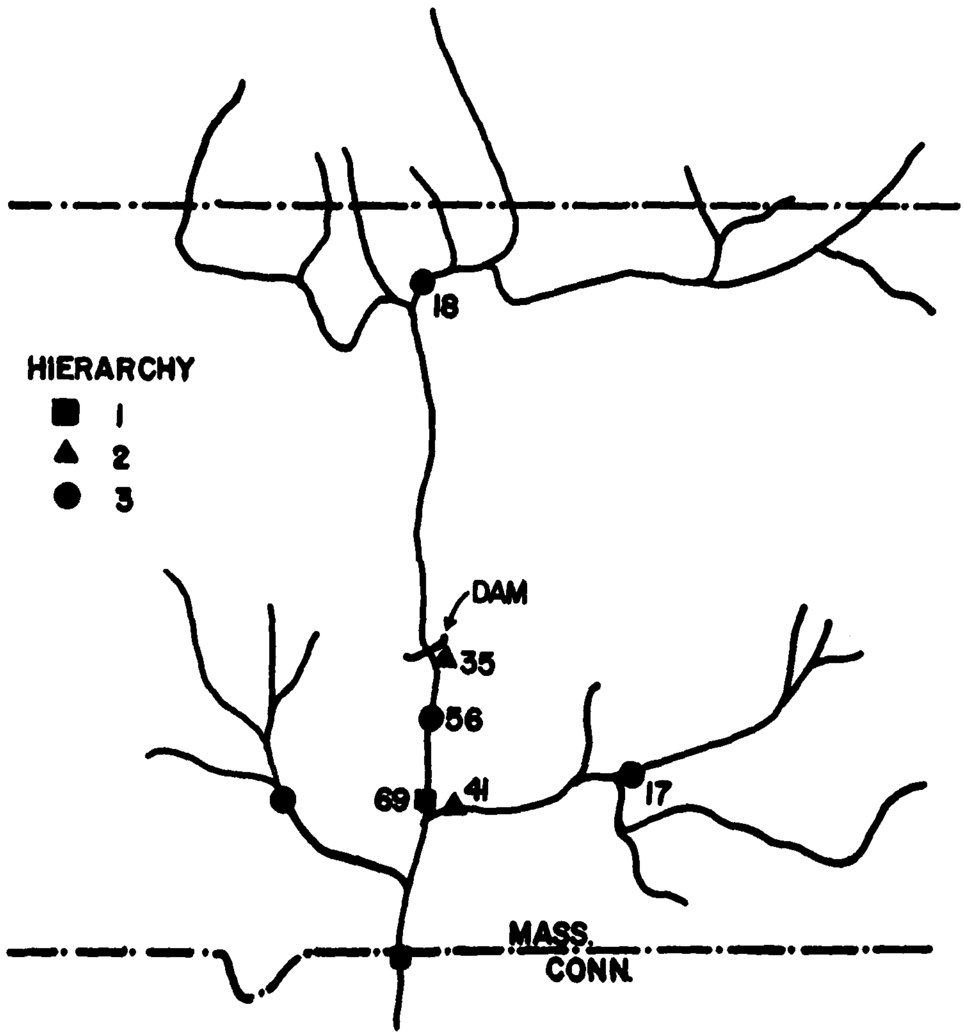
MONITORING SYSTEM
MATRIX

FIG. 1



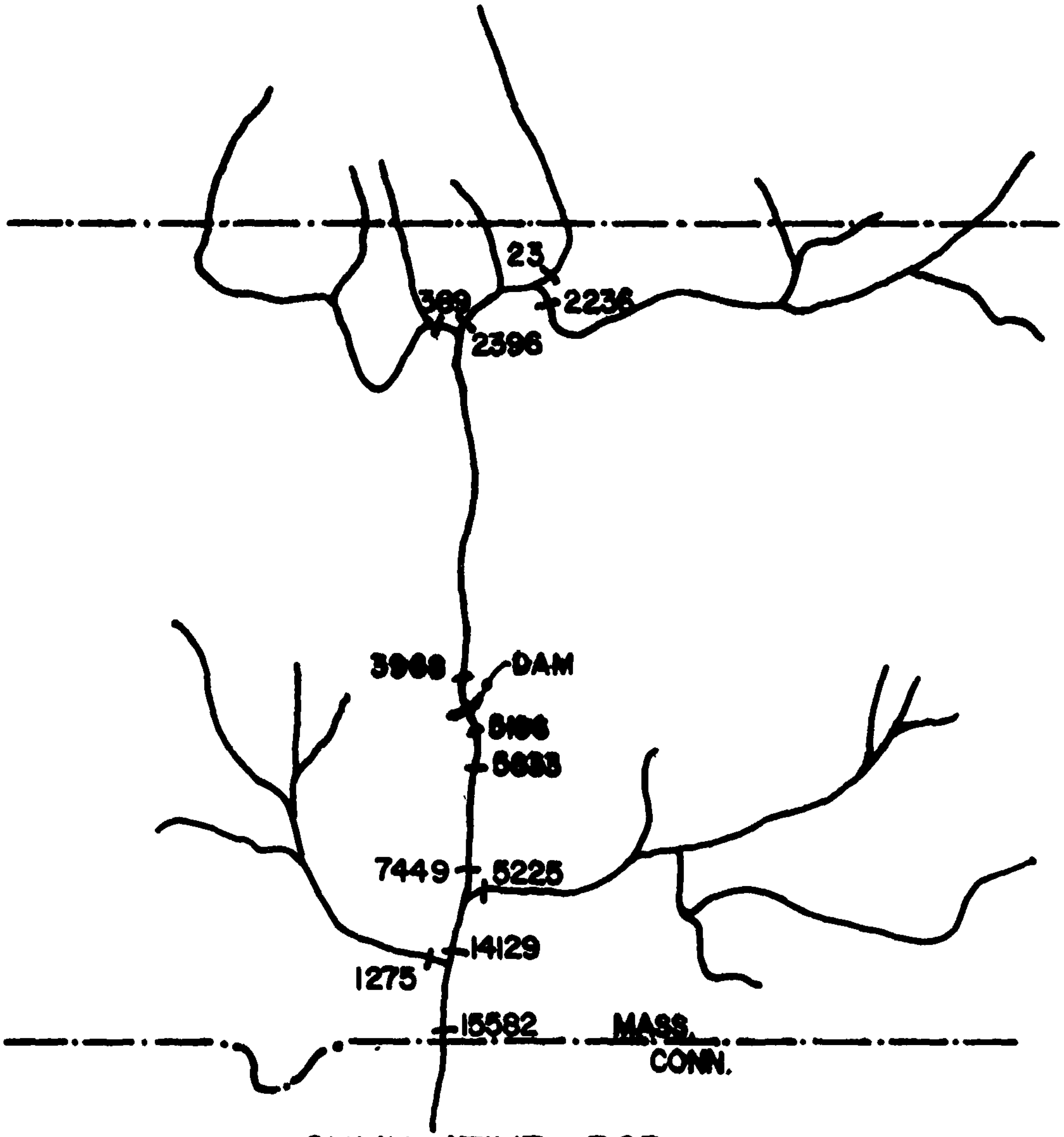

CUMULATIVE DISTRIBUTION
OF OUTFALLS

FIG. 2



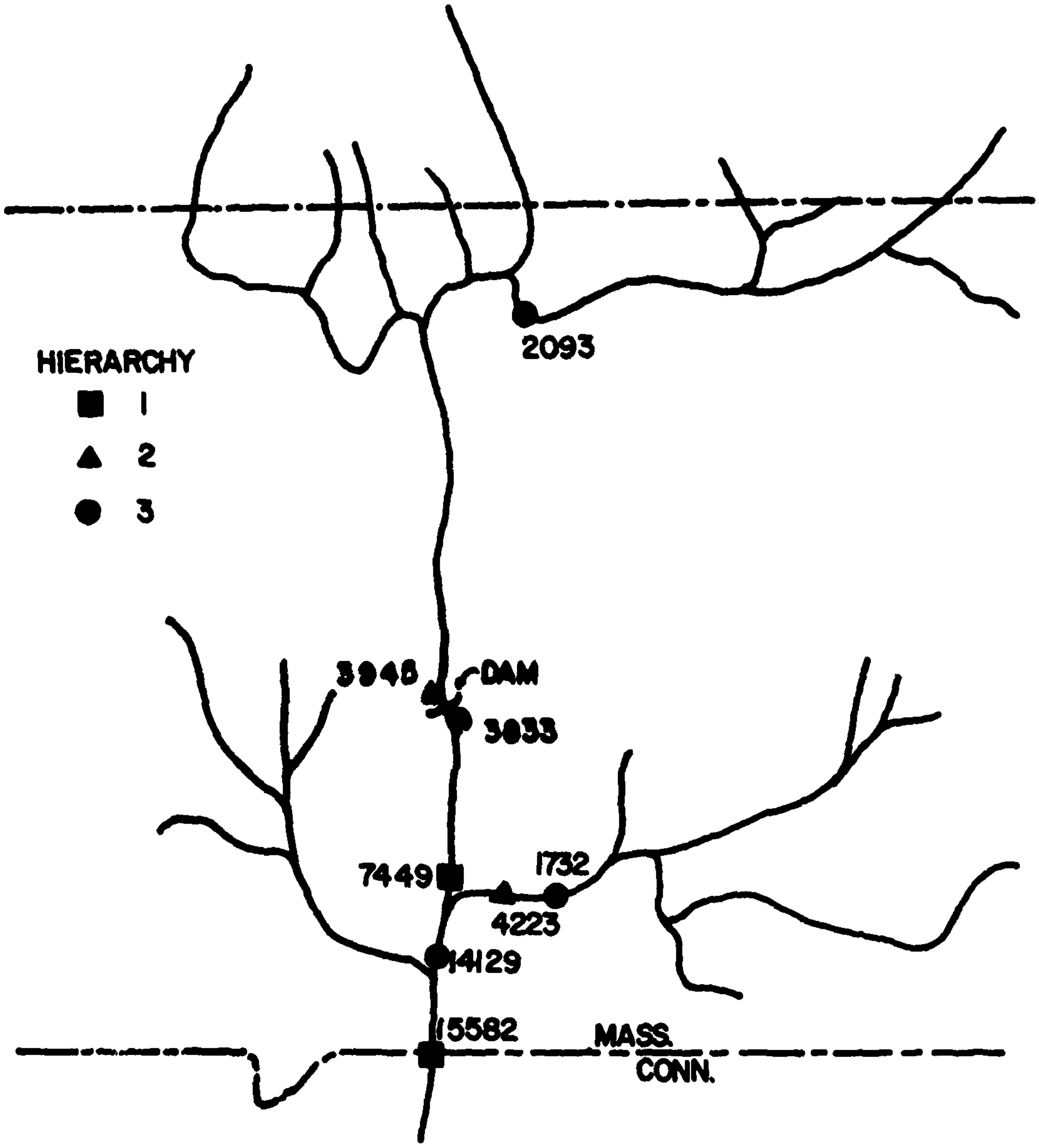

PLACEMENT OF SAMPLING STATIONS
BASED ON NUMBER OF OUTFALLS

FIG. 3.




CUMULATIVE BOD
LOADINGS

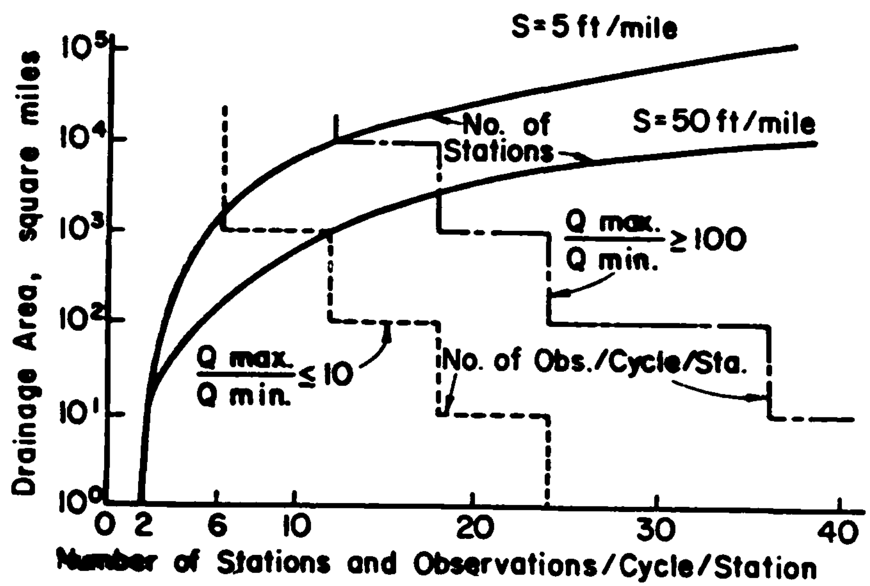
FIG 4.




PLACEMENT OF SAMPLING STATIONS BASED ON BOD LOADINGS

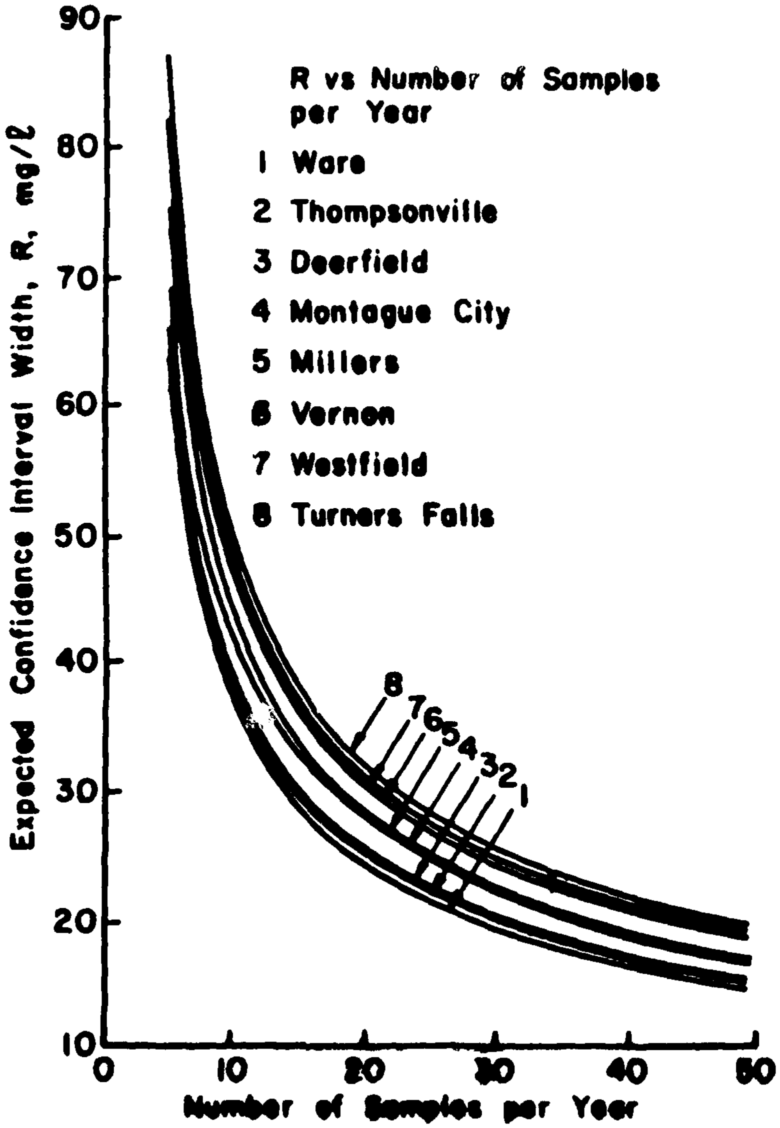
FIG. 5

Paper 5




The minimum number of sampling stations and sampling observations for water quality characterization of a river (Pomeroy and Orlob, 1967).

FIG. 6




Plot of the expected confidence interval width versus number of samples per year at eight sampling stations on the Green River.

FIG. 7

# COASTAL SAMPLING PROGRAM DESIGN

BY RICHARD JACKSON [1/]

Nineteen-eighty is the year of the coast, and I believe that during this year, we will see an increased attention to our activities and programs in the coastal area. I believe, therefore, that it is important that the work that we do in the coastal area be done as best we can and that we pay particular attention to those activities which are in the public eye during this year. This discussion will present, as a base, the procedures for designing a water quality survey in coastal areas. First, I'll list the proper steps to be taken in design; then I'll highlight those aspects which are particularly important to coastal studies, as opposed to inland studies, which were covered earlier.

What is the Coastal Area? The coastal area can be defined as the nearshore ocean, estuarine sounds, and bays, in which the Corps of Engineers does work. The kinds of activities that we are traditionally engaged in include baseline studies for survey reports. There we are concerned with impact analysis, identification of rare or unique areas, areas that can be modified to provide for environmental enhancement. We also conduct baseline studies for Section 404(b) analysis. Corps of Engineer districts do monitoring in coastal areas for maintenance dredging, and collection and analysis for ocean dumping, both for the transport of material for ocean dumping and site designation studies in the nearshore ocean. All of these kinds of activities are typical of those in which Corps of Engineers districts are involved in coastal areas.

[1/] Chief, Environmental Resource Branch, Wilmington District

The process of sampling design can be viewed as a series of steps taken in sequence. Those steps are: (1) define the objective; (2) collect background data; (3) prepare preliminary plans; (4) conduct field reconnaissance; and (5) prepare the final plan.

Define the Objective. Many of you are familiar with the term "management by objectives" as a business management tool. The same kind of concept holds true here. Management by objectives says that if you don't know where you're going, you're not likely to get there. So we want to define the problem and formulate an accurate statement of the objective for doing the water quality work. Our concerns here may be to establish baseline or benchmark from which future changes can be measured; to monitor impacts of existing activities; to provide input for mathematical models or input to physical models; or to provide management data for decisions. An important aspect is the scope of the studies that we make, that is, to what extent will we try to answer the key questions, and here, of course, we are limited by time and by money available to do work. In sampling design we must be realistic and establish goals which are reasonable.

Once our objective is established, then we need to coordinate the statement of the objective and the need with those who have an expertise or special interest in our sampling. These people may include the Environmental Protection Agency (EPA), the various offices of the State in which we are doing the work, the Coastal Engineering Research Center, Waterways Experiment Station (WES), or a local university. We need to reach a consensus on the problem definition and the statement of objective before we proceed with the next step. The consensus we seek is somewhat the completion of a scoping kind of activity, such as is defined in our current NEPA regulations.

Collect Background Data. The next step in our sampling program design is to collect background information. All sources should be checked: STORET, the U.S. Geological Survey Water Quality Data Reports, Sea Grant publications, individual agency files, other agency EIS's, and NOAA's Environmental Data and Information Systems. Check all sources. Check with local industry and universities for unpublished data that may be found in manuscripts, in thesis, unpublished dissertations. All of these sources can contain valuable information on the study area in question that can be used in preparing our sampling program design. Always look for maps and photographs which can be useful for locating sampling stations and give us a better information base. We want here to be looking at the USGS quad sheets, orthophoto quads, the ASCS photos, National Ocean Survey and even county road maps.

Prepare the Preliminary Plan. The purpose of this step is to bring together information that we have compiled, couple it with our expertise and our statement of the problem, and mold them into a workable plan that can be reasonably accomplished. One of the questions that we will have to address in this step is: What are the parameters that we will be be measuring? That goes back to the object of the study itself. For instance, if we are interested in whether State water quality standards are being met or not, then we will certainly go to the standard, and it will define clearly those parameters which we ought to be measuring. So the statement of the objective of the study defines for us, in many instances, those water quality parameters to be measured. Other questions to be answered are the method of analysis, collection techniques, and instrumentation. Will we have to train technicians to do special sampling or special care in the collection or in the analysis? Do we need to alert them to any special precautions to avoid contamination of the sample? Think about all of these at this step in preparing the preliminary plan.

One of the most important aspects of preparing the preliminary plan is the station location. This concept deals with the spatial distribution of the parameters that are selected for analysis. Each station essentially represents some area or reach in which we assume a homogenous condition to exist. The factors that we need to be especially aware of in coastal areas are horizontal and vertical stratification and existence of point sources of pollution or inflowing streams. In many cases, inflowing streams provide for horizontal stratification that needs to be taken into account. Also, in terms of vertical stratification, especially in estuaries, we may find temperature and salinity changes in vertical directions. These changes can cause our stations to be nonrepresentative. Statistical methods are available for selecting stations. The prerequisites for statistical sampling or statistical methods are a good knowledge of the variability of the parameters, confidence level for the data that we have and the population distribution. If the population is normally distributed, then we can, of course, go to random sampling for our stations. If the sample is not homogenous, then we may use a stratified random sampling. Before launching into statistical sampling though, I think we need to consider some questions that will be important. What decisions will be based on this data; that is, what is the sensitivity to errors of our population estimate? Do I really have enough information to estimate the mean and the standard deviation, and do I really have enough money to collect meaningful, statistically valid data? If not, then how do we choose sample station locations? Judgment, knowledge, and experience are important, along with the advice of others, in identifying stations nonstatiscally. We make assumptions about the population and we select stations to fit our needs.

Now another question we want to deal with is the frequency data collection. How often do we collect data at our station? Background data on tides, seasonal, and even daily differences become important. Our knowledge of how the various parameters change with time guides us into making a determination of the frequency. Data can be collected on a continuous basis, daily, periodic intervals during the day, during flood

tide only, etc. At the end of this step, we should have a written description of the problem, the objective, and the sampling effort. We should have maps showing sample station locations, parameters to collect, method of collection, methods of analysis, frequency of sampling, and our best estimate of the time and cost. We should have all of that put together, in essence, in a scope of work so that if we wanted, we could go out and contract with someone for this work.

Conduct Field Reconnaissance. The next step in our sampling program design is to conduct a field reconnaissance. This is an important step. It cannot and should not be passed over for this step confirms those assumptions we just made in designing the preliminary plan. We need to determine locations for lodging, sources of water, dry ice, electricity, or any other special needs for the sampling effort. Locate boat ramps, etc. Take your boat with you. Run through several of the sampling stations; physically go out and try to anchor on the station and see how long it takes to run through a collection. Make observations of the current conditions, tides, waves, and boat traffic. The purpose of the reconnaissance is simply to make sure that your plan will work. You don't want to get into the field and find out that you have a sand bar where your station is on low tide. Where there is some reason that program will not work, it can be found out through the reconnaissance.

Prepare the Final Plan. The last step in sampling program design is to prepare the final plan. This process is somewhat iterative in that we want to review again the statement of the problem, the objective and then, using the observed field data from our reconnaissance, make adjustments in the plan. Many times we will find that these adjustments are critical to the success of the sampling. All that now remains is to implement the plan. Make sure that we monitor the fieldwork for compliance. Make sure that you go out and watch and see that the technicians are collecting the samples as you asked them to do. Be aware of Murphy's Law: (a) Nothing is as easy as it looks. (b) If anything can go wrong, it will. (c) It always takes longer than you think it will.

There are some special concerns in sampling program design for coastal areas. One of these is tides. Tides are important for nearshore areas where station access at low tides must be confirmed. It should also be noted that parameters change with tides and can make an important difference. Strong flood tide currents can force rivers to flow upstream. Strong ebb tide currents can make navigation treacherous. All these concerns will be important in designing your program and in implementing the program in a safe way. Seawater can interfere with standard tests. Check the analysis method to make sure that you don't have an interference with the seawater. Strickland and Parsons is a good reference for seawater analysis of water samples. Then, of course, corrosion is always important in coastal areas. Equipment must be constantly maintained or it will not work. Winds, waves, weather often cause problems. Northeasters or other strong coastal storms can make our sampling impossible. So when you are designing your program, don't forget to account for these kinds of conditions and allow for some contingency or some bad-weather day estimate. In coastal areas the equipment that is used is often larger and heavier than that used in freshwaters. This equipment may require davits or other machinery on board that is not used inland. I believe that most ocean work will have to be done by contract since most Corps office districts do not have large vessels with the special equipment to do ocean work. Finally, I think we need to review or beware of the seasonal occurrence of biological species where they are involved in our sampling effort. For instance, many of the anadromous fish are in the estuary or passing through only at a certain time of the year. The same is true of other species which only spend a part of their life in the estuary. The rest of their life is spent either in the ocean or in some other area.

In summary, a water quality sampling program in the coastal area needs to be formulated, using a set of five steps: (1) Define the object; (2) collect the background data; (3) prepare preliminary plan; (4) conduct reconnaissance; and (5) prepare the final plan. A conscientious effort, following these five steps and being aware of special concerns or precautions for the coastal areas, can result in an excellent program that will provide meaningful data within a cost effective framework.

# PROTOTYPE STUDY: OXYGEN INJECTION SYSTEM

BY RANDALL C. MILLER[1] and JAMES W. GALLAGHER[2]

## INTRODUCTION

The Savannah District, U.S. Army Corps of Engineers, operates and maintains two multipurpose hydroelectric projects on the Savannah River between Georgia and South Carolina.[1] The Hartwell Dam and Lake project, the most upstream project is located approximately 7 miles below the confluence of the Tugaloo and Seneca Rivers about 7 miles east of Hartwell, Georgia. The lake has a surface area of 55,950 acres and a storage of 2,550,000 acre-feet. The plant was placed in operation in 1962 as 264-MW plant, operating at an average head of 180 feet. The Clark Hill Dam and Lake project is located about 67 miles downstream of Hartwell. Clark Hill Lake has a surface area of 71,000 acres and a storage of 2,510,000 acre-feet of water. Clark Hill was placed in operation in 1952 for peaking power, but is also required to maintain average daily flows above a certain level for navigation on the Savannah River. Installed capacity at Clark Hill is 280 MW at an average head of 146 feet. Currently the Savannah District is constructing the Richard B. Russell Dam and Lake project 30 miles below Hartwell Dam and 38 miles above Clark Hill Dam. When completed Russell Lake will have a surface area of 26,653 acres and a storage of 1,026,244 acre-feet of water. Russell is currently authorized as a 300-MW peaking plant, although feasibility studies for inclusion of pumped storage are presently underway. If pumped storage is authorized for the Richard B. Russell project, pump turbines will be installed with an additional capacity of 300 MW. Average generation and pumping head will be approximately 145 feet with the upper end of Clark Hill Lake serving as the pumping forebay.

Like most deepwater bodies, these lakes undergo, or in the case of Russell Lake will undergo, lake stratification. This phenomenon results from the difference in densities between the surface and subsurface water which is induced by the temperature variation in the water column. As the tributary and surface waters warm, the difference in density between the surface and bottom waters begins to restrict vertical circulation of the lake. As the result of this restriction of circulation, three layers develop: the epilimnion, the well mixed surface layer which receives oxygen from the atmosphere; the hypolimnion, the bottom strata which is typically below the zone of light penetration, and lacking free circulation with surface waters, has no potential to renew dissolved oxygen concentrations which are gradually exhausted through respiration and decomposition of biological activity; and the thermocline, which is the transition between the upper and lower strata and which exhibits the maximum temperature gradient.

In all these projects the turbine intakes are located far below the surface in the hypolimnion, so that water level fluctuations for flood control do not affect power generation. Therefore, it is this lower layer of water that is released from these projects year-round, and during the summer, the waters released have progressively reduced oxygen levels.

The location of the intakes in the lower layer of the lakes has made possible for the public living in the southeast the desirable benefit of cold water trout fishing not otherwise available in southern latitudes because of the excessive summer temperatures characteristic of streams in this region. In an effort to take advantage of these unusual cold water conditions in the reaches of the river below these projects,

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the state regulatory agencies have in the past designated these areas as trout streams requiring that the water temperature not exceed 70° F, and the daily average dissolved oxygen level be maintained at 6 ppm (parts per million) and not fall below 5 ppm. But herein lies the problem: the same deep impoundment which releases the cold water needed by the trout to live during the summer heat cannot at the same time by natural means insure enough oxygen in bottom waters to make downstream releases satisfactory for trout.

Interagency Involvement

This problem has received much attention from Federal and State agencies. On 23 March 1972, the U.S. Environmental Protection Agency (EPA) called a conference, entitled the Middle Reach Savannah River Enforcement Conference on the matter of pollution of the interstate waters of the Savannah River and its tributaries from Clark Hill Dam to 75 miles downstream from Augusta, Georgia. Based on information and testimony presented at the conference, the conferees unanimously agreed on several conclusions and recommendations.[1] One conclusion was that the releases from Clark Hill Dam may violate water quality standards of the Savannah River, especially with respect to dissolved oxygen and disolved minerals. The conferees recommended that the Corps of Engineers, in cooperation with the EPA, should investigate possible violations caused by releases from Clark Hill Dam, and report to the conferees their findings and any necessary remedial action which must be instituted to correct any deficiencies. On 28 March 1973, the Savannah District reported to the Chairman of the Enforcement Conference the results of their investigation. This report concluded that the releases from Clark Hill Dam meet all established water quality standards except the dissolved oxygen standard during the late summer and early fall months due to thermal stratification. A joint EPA - Corps of Engineers task force was then formed to investigate and recommend means of resolving the problem at Clark Hill. After reviewing possible solutions to the Clark Hill water quality problem, it was decided that oxygen injection would provide the best method for a solution.

During this time the Savannah District was involved in coordinating the planning of the Richard B. Russell Dam and Lake project with the States of Georgia and South Carolina. One concern of the State of Georgia was that the operation of the project be in compliance with state water quality standards. The cost-sharing agreement between the State of Georgia and the Federal Government for the development of the recreational areas of the project included the stipulation that the operation of the project will meet state water quality standards. In addition, in July 1972, the Georgia Department of Natural Resources requested the formation of a technical committee to analyze the water quality matters relating to the Richard B. Russell project. The objective of the Committee, officially titled the Joint Federal-State Technical Committee on Water Quality at Richard B. Russell Lake, was to evaluate the thermal and dissolved oxygen characteristics of the Richard B. Russell project, with and without pumped storage, as an intergral part of the Hartwell-Clark Hill Reservoir System, including the following specifics:

a. Maintenance of Federal and State Water Quality Standards.

b. Maintenance of a cold water fishery in a 10-mile reach downstream from Hartwell Dam.

c. Development of a warm and cold water fishery within Richard B. Russell Lake.

d. Maintenance of a warm and cold water fishery within Clark Hill Lake.

In its final report the Committee observed that the above water quality objectives could be met with the artifical addition of oxygen.[2]

Reponding to this need for a method capable of meeting state water quality standards in hydropower releases, the Savannah District, for the past 5 years, has investigated the feasibility and conducted field tests of an oxygen injection system at Clark Hill Lake.

Feasibility Study

A quantification of the dissolved oxygen deficiency at Clark Hill and an examination of alternative solutions was performed by Speece in 1974.[3] The total quantity of water discharged on the average was determined to be 13,500 acre-feet. Assuming that in the critical period occasionally the released water would be totally devoid of oxygen, 6 ppm of dissolved oxygen would have to be provided daily. Therefore, a maximum 110 tons of oxygen would have to be artifically supplied. Based on the recorded seasonal dissolved oxygen variation in the releases from Clark Hill Dam, 7,500 tons of oxygen would have to be supplied seasonally to maintain a dissolved oxygen level of 6 ppm.

The alternative solutions examined included surface aerators, diffused air injection, spillway aeration, penstock air injection, multilevel penstock intakes, submerged weirs, oxygen injection into the penstocks, side stream oxygenation, localized destratification of the lake, pulsed oxygen injection through fine pore diffusers into the reservoir at the face of the dam (with the oxygen injection rate matching the water discharge rate), and continuous oxygen injection through porous diffusers into the lake at a point several days travel time upstream of the dam. The latter alternative was identified as the most feasible alternative. With an on-site Government-owned cryogenic plant to supply the oxygen, the initial capital cost of the system was at that time $2.2 million with a yearly operation and maintenance cost of $73,000.

Field Test

As a first step in testing the performance of oxygen injection through fine pore diffusers, a small scale system capable of providing sufficient oxygen for the discharge of one turbine was installed adjacent to the dam face and operated in a pulsed mode by Speece, et al, in the summer of 1975.[4] This made it possible to rapidly monitor the oxygen level in the discharge and determine the oxygen absorption efficiency immediately.

Three oxygen diffuser racks were constructed. Basically, each rack was a pipe frame which served as a structural support for the individual diffusers as well as a manifold to distribute the oxygen from the supply hose to each diffuser. The diffuser plates were porous carborundum having an area of 1 square foot each. Ten diffusers per rack were located 10 feet on center. The standard permeability of diffusers was 2 feet per minute at 2 inches of water pressure. The bubble size generated under these conditions was approximately 2 mm diameter. The diffuser loading rate was 2,400 pounds of oxygen per diffuser (1 $ft^2$) per day at 140 feet of submergence. This is equivalent to about 4 actual cubic feet per minute per square foot of diffuser at this depth and oxygen loading rate.

The three diffuser racks were positioned 10 feet from one intake. A bridle of 1/4-inch cable was attached to the rack to facilitate placement. A 1-inch flexible hose supplied gaseous oxygen to each rack from a liquid oxygen tank located on the dam face. Oxygen was metered to each rack and the dissolved oxygen content was monitored at a point in the draft tube beneath the turbine wheel. Lowered oxygen absorption efficiencies were noted when discharges were made from the turbine with its intake 10 feet from the racks. However, marked improvement in oxygen absorption efficiency was noted when discharges were made from the turbine with its intake 120 feet from the racks. It was concluded that maximum oxygen absorption efficiencies were obtained by insuring that the bubbles in the rising plume were not swept prematurely into the penstocks. This required that the diffuser racks be located at least 100 feet horizontally from the intake. Dissolved oxygen concentrations of 6-8 ppm with oxygen absorption efficiencies of 85 percent were obtained with the diffuser racks located at least 100 feet from the intake.

It was concluded from these tests that it was technically feasible to dissolve oxygen in a pulsed mode that was matched to the water discharge rate. However, as mentioned earlier, the feasibility study recommended continuous oxygen injection at an upstream point in the lake over pulsed oxygen injection at the face of the dam. Pulsed injection of oxygen to match the water discharge rate involves matching the peaking discharge pattern which normally occurs less than 12 hours each week day and even less on weekends. With on-site cryogenic oxygen being produced in the gaseous state at a uniform rate, compression and storage would need to be provided to match the production with the usage rate. This would increase the capital costs of the oxygen production facility. Therefore, it was decided that field tests should be conducted to evaluate the feasibility of continuous injection into a diffuser system located approximately 1 mile upstream of the dam.

The field tests of the continuous injection system began the next summer.[5] The tests were divided into three phases. Phase I was an evaluation of the oxygen absorption efficiency of various diffusers. The experimental system constructed on the face of the dam consisted of an 11-foot diameter bubble collection hood with off-gas totalizer and analyzer. The diffuser to be tested was lowered to the bottom of the lake. Oxygen was fed to the diffuser at rates of 0.3, 0.6, 1.0, 2.0, and 3.0 acutal feet per minute. The bubble collection hood was positioned above the diffuser at heights of 10, 50, and 130 feet. The gas collected from the diffuser through the hood was measured and analyzed for percent of oxygen. In this way, the oxygen absorption efficiency of each diffuser was determined. In this test diffusers with a standard permeability of 0.5 to 2.0 fpm were identified as the optimum diffusers.

Phase II involved tests of the diffuser racks to determine the elevation in the water column at which the oxygenated water would come to equilibrium. The three diffuser racks from the pulsed injection test previously described, along with two racks constructed to the same specifications, were located about 300 feet in front of the penstock intakes. The racks were aligned roughly parallel to the dam about 60 feet apart. A manifold was mounted on a raft and distributed vaporized liquid oxygen to the racks from the liquid oxygen storage tank located on the face of the dam. Oxygen was injected at rates varying from 57 to 100 pounds per minute, and temperature and dissolved oxygen profiles were taken in the forebay while monitors on the seven draft tubes recorded the dissolved oxygen variations in the turbines. The data revealed that 80 percent of the oxygen remained in the hypolimnion, accessible for downstream release, when injected at these rates.

Phase III of the study involved installation of nine diffuser racks at a location approximately 1-mile upstream of the dam in water approximately 130 feet deep. Due to the availability of the diffusers, 10.0 fpm diffusers were installed in these racks rather than diffusers in the 0.5 to 2.0 fpm range identified as optimum in the Phase I

study. The diffusers racks were placed in semicircular pattern with a spacing of about 100 feet on center. Again, vaporized liquid oxygen was fed from a liquid oxygen storage tank through a manifold mounted on a raft to the oxygen diffuser racks. Oxygen was injected at a rate of 100 tons/day which would have been sufficient to provide a dissolved oxygen concentration of 6 ppm in the average discharge from Clark Hill Dam. Temperature and dissolved oxygen concentrations were recorded at fixed sampling stations within the lake between the dam and the diffuser rack location, and also 1/4 mile upstream from the diffuser racks where background profiles were obtained. The automatic dissolved oxygen monitoring system which sampled water passing through the turbines was also operated during this phase of study. Oxygen was injected continuously for a period of 8 days after which time the lake began to destratify terminating the test. The highest dissolved oxygen concentration recorded in the turbines was 4.1 ppm which occured about 6 days after oxygen injection started. The background dissolved oxygen before oxygen injection commenced was 0.5 to 0.8 ppm. Only about 30 to 40 percent of the oxygen that was injected appeared to eventually reach the turbines. The low oxygen absorption efficiency was due to two factors. First, as stated earlier, the diffusers on the rack were not the most efficient as determined in Phase I of the study. Second, the close semicircular spacing of the diffuser racks and high injection rates per diffuser caused localized destratification in the vicinity of the diffuser racks which resulted in the dissolved oxygen-rich water coming to equilibrium in the upper level of the lake where it was unavailable for dissolved oxygen enrichment of the turbine discharges. It was determined that improvements in the performance of the oxygen injection system could be realized by lowering the injection rate per diffuser by quadrupling the number of diffusers per rack, equipping the racks with the optimum 2 fpm diffusers, and spreading the racks across the lake cross section.

These improvements were made to the system and field tests were conducted in the summer of 1977. The nine racks were fitted with 40 square feet of diffusers of 2 fpm standard permeability. The racks were placed across the lake cross section one mile upstream from the dam and the racks being spaced approximately 300 feet apart with the first rack located approximately 1,200 feet from shore. The manifold from the test of the previous year was eliminated and a 3-inch diameter oxygen supply hose was floated on the surface of the lake and guyed with anchors. This supply hose delivered vaporized liquid oxygen from the storage tanks on the shore to the diffuser racks via 1-inch diameter hoses. Oxygen was injected continuously for 30 days at a rate of 100 tons/day, and disolved oxygen and temperature were monitored in the lake and the turbines. During this period of oxygen injection, dissolved oxygen concentrations of 4 to 5 ppm were maintained with an absorption efficiency of 50 percent. Although this represented an improvement over the results from the previous year, the goal of 6 ppm dissolved oxygen was still not achieved and the absorption efficiency was still unacceptable. Although the lake did not destratify in the vicinity of the racks, pumping of the oxygenated water occured causing it to reach the surface where it warmed and returned to an intermediate layer generally above the turbine withdrawal zone. It was determined that the pumping was due to the four-sided diffuser configuration of the racks, and that the pumping could be eliminated by installing baffles over the diffuser racks to deflect the oxygenated plume or by employing a linear diffuser configuration.

The results of the 1977 test led to the small scale tests performed between July and September 1978 to evaluate the effects of plume deflectors, loading rate, and diffuser configuration on the performance of the oxygenation system.[7] During these tests, oxygen was injected for an 8-hour period from 12 midnight to 8 a.m. through a "ribbon" diffuser 40 feet long and 1 foot wide located perpendicular to the face of the dam. To identify the zone where the oxygen-enriched water came to equilibrium, dissolved oxygen profiles were taken at 0, 100, 200, and 400 feet from the diffuser rack in the morning before the turbines began discharging. To compare

the effectiveness of this modified diffuser configuration with the four sided square configuration used in the 1977 test, a diffuser rack used in the 1977 study was also installed and operated at the face of the dam. The oxygen loading rates applied to the diffusers were 125, 250, 375, 500, and 2,000 pounds per square foot of diffuser per day. At the beginning of the tests, it was discovered that the 250 and 500 pound per foot$^2$ day loading range was optimum; therefore, the majority of the testing was conducted in this range. Three different baffle configurations were evaluated: a 1-inch diameter PVC pipe grid with 1/2-inch clear spacing, 1 1/2-inch wood slats with 1 1/2-inch clear spacing, and 6-inch wood slats with 1-inch clear spacing. All of the plume baffles consisted of a frame 6 feet wide and 40 feet long and were evaulated at 25, 50, and 75 feet above the diffuser. Primarily, the data collected from these tests indicated that the linear diffuser configuration is superior to the four sided diffuser configuration in depositing the oxygenated water in the withdrawal zone. The most effective plume deflector was the PVC configuration. However, generally the effects of the baffles on the behavior of the oxygenated plume were minimal.

## Planned Further Studies

The small scale tests of 1978 indicated that a linear configuration of diffusers is effective in decreasing the excessive pumping of oxygenated water. This linear configuration will be employed in a full scale prototype by the use of a proprietary "dome diffuser" system. This system is currently being fabricated and installed at Clark Hill Lake 1 mile upstream of the dam. This system consists of 7-inch diameter dome diffusers bolted to a PVC baseplate on a 4-inch schedule 80 PVC pipe by a hollow bolt that serves as both a fastener and an orifice which throttles the oxygen filling the dome. Oxygen is fed through the 4-inch PVC pipe, which serves as the mounting for the diffusers as well as the supply manifold, then through the orifice to the diffuser. The diffusers have a standard permeability of 2 feet per minute, and they are spaced 1-foot oncenter. Twenty-five hundred feet of the diffuser system will be installed across the lake cross section in 100-foot sections. Flexible hose will separate each section and the system will be positioned 10 feet off the lake bottom. The testing of this prototype will be conducted between August and September 1980.

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# TABLE ROCK TAILWATER TROUT FISHERY -- VALUE, USE, AND DISSOLVED OXYGEN PROBLEM [1]

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## INTRODUCTION

Lake Taneycomo was formed in 1913 when the Empire District Electric Company built Powersite Dam on the White River in Taney County, Missouri (Fig. 1). Taneycomo (Table Rock Tailwater) was transformed from a warmwater to a coldwater lake in 1958 when Table Rock Dam was constructed upstream by the U.S. Army Corps of Engineers. Water (3 to 13°C) is discharged at a rate of 20 to 15,000 DSF into Lake Taneycomo from Table Rock Lake through four penstocks, 51 meters below the surface. The cold water resulted in a substantial decline in the warmwater fish populations. Subsequently, the Missouri Department of Conservation stocked rainbow trout (Salmo gairdneri) and successfully established a coldwater fishery (3). The U.S. Fish and Wildlife Service has provided about 45% of the trout.

Lake Taneycomo is 32 kilometers long, and has a surface area of 700 hectares. The upper 5 kilometers are shallow, with depths directly related to water releases from Table Rock Dam. The maximum depth of the lake is about 12 meters, near Powersite Dam. Lake Taneycomo is long and narrow, and current is often strong at Branson, about 14 kilometers downstream from Table Rock Dam.

The Missouri Water Pollution Board established a minimum standard of 6 mg/l for dissolved oxygen in Lake Taneycomo after holding public hearings between 1966 and 1968. The Missouri Clean Water Commission revised the water quality standards for Missouri in 1973 and submitted them to the Environmental Protection Agency for approval as Federal Water Quality Standards. They were approved and the minimum standard for dissolved oxygen in all trout waters in Missouri, including Lake Taneycomo, was set at 6 mg/l.

1 This research is being conducted by the Missouri Department of Conservation (MDC), Fish and Wildlife Research Center, 1110 College Avenue, Columbia, MO, 65201, with 100% funding provided by the U.S. Army Corps of Engineers -- Little Rock District. A final contract report (DACW03-78-C-0057) will be submitted by 3 November 1980.

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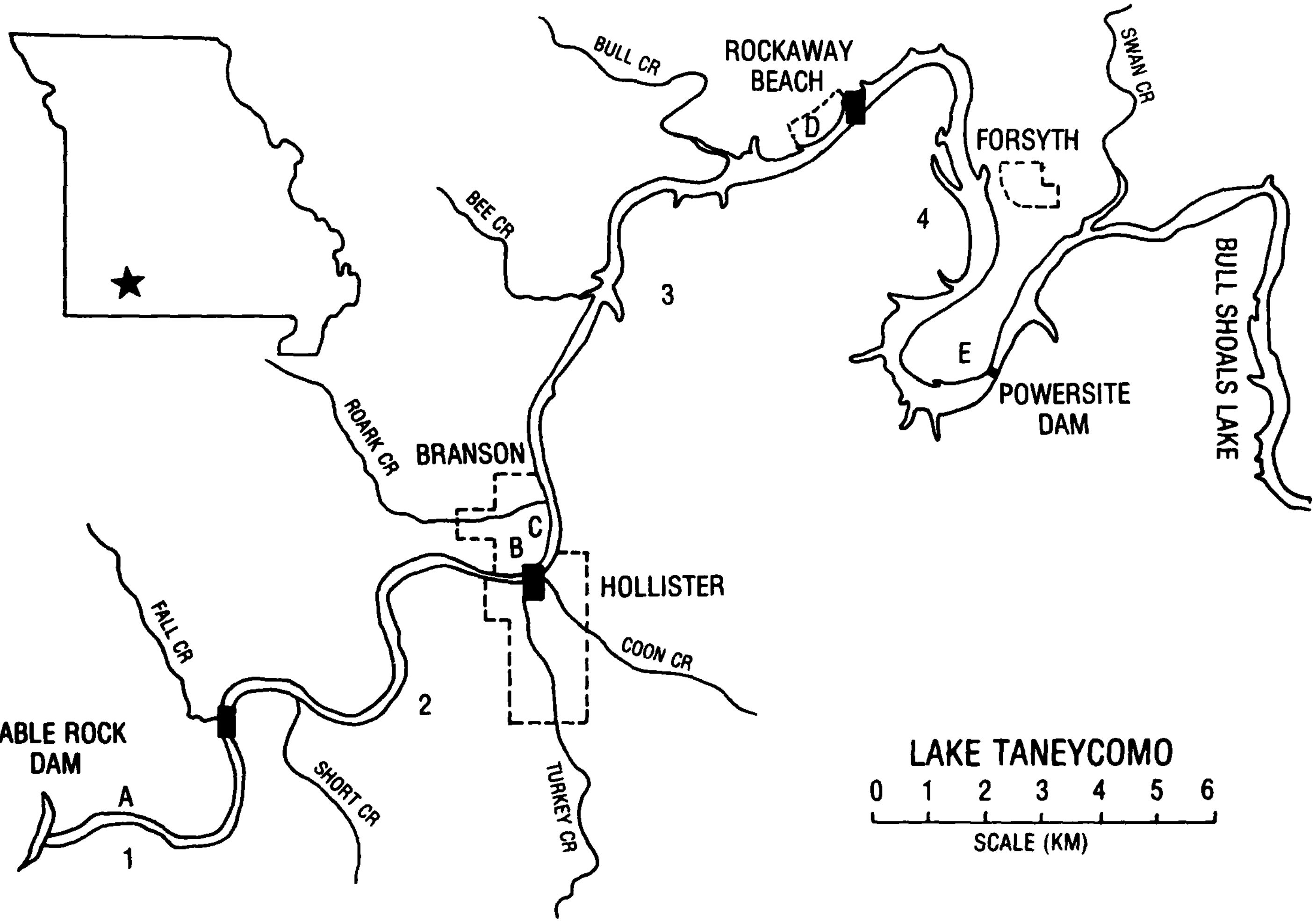


Figure 1. Angler interview sites (A-E) and study areas (1-4) on Lake Taneycomo, Missouri.

Dissolved oxygen concentrations below 6 mg/l have been measured in upper Lake Taneycomo periodically each fall since 1959. The low levels are caused by the discharge of oxygen deficient water from the hypolimnion of Table Rock Lake. The pattern is predictable; only the severity changes from year to year. Reasons for the differences are related to the amount of rainfall, temperatures in the hypolimnion of Table Rock Lake, the amount or kind of organic material washed in or produced, and the amount and pattern of water releases. The problem at Lake Taneycomo did not become acute, however, until after 1968 when levels of dissolved oxygen below 2 mg/l were often recorded.

The U.S. Army Corps of Engineers has attempted in various ways to alleviate the low dissolved oxygen situation at Lake Taneycomo. Surface water was released over the spillway of Table Rock Dam. However, this warm water did not mix well with the cold turbine discharge and the technique was discontinued.

An air injection system, consisting of ten large diesel-powered air pumps, was installed in 1971 in the turbines to determine its feasibility. The air injection equipment was used in the fall of 1972 in conjunction with restricted generation rates in an attempt to maintain dissolved oxygen levels above 5 mg/l, 5 kilometers downstream from Table Rock Dam. The efficiency was less than expected and the system only furnished enough oxygen for two of the four turbines when they were operated at full capacity.

The Corps of Engineers also tried to raise dissolved oxygen levels by diffusing air into Table Rock Lake just above the dam. This technique failed to increase dissolved oxygen significantly in the turbine discharge. Injections of pure oxygen were tested in 1973. Sufficient oxygen could be injected to raise the dissolved oxygen level to 6 mg/l, but the system was less efficient than expected. When generating at full capacity, about 6.8 metric tons of oxygen per hour were required to maintain the dissolved oxygen in the discharge at 6 mg/l. The cost for the oxygen at this rate was $8,000 every 24 hours. Limited oxygen supplies and higher prices in 1974 curtailed this effort.

Another experiment involved the passage of water through the sluice gates at Table Rock Dam in 1978. The turbulence of the water increased the level of dissolved oxygen, but it also killed fish near the dam and increased turbidity. A serious drawback of this technique is the potential for structural damage at Table Rock Dam due to cavitation. Therefore, future use of this method is unlikely.

The current operating policy calls for a combination of techniques to maintain 4 mg/l of dissolved oxygen in the Table Rock Dam discharge. Reduced water releases in the fall provide maximum benefits from incorporation of air through the vent tubes. A small supply of liquid oxygen is also maintained for emergency use.

The research described in this paper was proposed to determine and quantify the effects of varying levels of dissolved oxygen on the Lake Taneycomo trout fishery. We have five main objectives: (1) develop a socioeconomic profile of the study area; (2) estimate the socioeconomic value of the Lake Taneycomo fishery; (3) determine angler success and effort for 1 year; (4) estimate the effect of low levels of dissolved oxygen on angler success; and (5) quantify the indirect economic impact of low levels of dissolved oxygen on the area economy.

This report is an overview in which we present preliminary results of our 28-month study. The project is scheduled for completion in November, 1980, and a final report of the results will be available.

## SOCIOECONOMIC VALUE OF THE FISHERY

The study area is defined as the geographic area under the direct economic influence of the Lake Taneycomo fishery. We used Taney County because it is within this area that Lake Taneycomo anglers and their groups spent time and money. The population of Taney County is rural, with below-average income. Since the 1950's and the addition of two large reservoirs, the area has become an important retirement center. The tourist industry has grown considerably and has become the foundation of the area economy. Sales in the retail trade and service industries currently account for about 70% of the business activity in the area.

We conducted a telephone survey of 500 Lake Taneycomo anglers to determine their characteristics, activities, and preferences, and to isolate that portion of economic activity which can be directly attributed to the Lake Taneycomo fishery. Interviews were conducted each month from 1 June 1978 to 31 May 1979 to select a representative sample. Names of heads of households used for telephone interviews were collected at random from people observed fishing on Lake Taneycomo. Anglers were telephoned within 1 month so details of their trips could easily be recalled.

Anglers who were residents of Taney County (n=55) had lived in the area an average of 7 years and were 56 years old on the average. Over half (51%) were retired. The annual family income of resident anglers averaged $15,270. More respondents (26%) moved to the area because of trout fishing at Lake Taneycomo than any other reason. Resident anglers averaged 104 days of fishing a year at Lake Taneycomo.

Anglers who were non-residents of Taney County (n=445) have been going to the area an average of 9.7 years, with 13.5% visiting for the first time. The average non-resident made 9.7 trips per year to the area and stayed an average of 5.1 days. Over half of the non-resident anglers (54%) traveled over 322 kilometers

one way to get to Lake Taneycomo. Some non-resident anglers and their groups (43%) participated in activities other than trout fishing while in the area. The most popular attractions were country music shows (17%), Silver Dollar City (16%), sight-seeing (14%), and shopping (11%). Trout fishing was the most enjoyable activity (93%) and primary reason for the trip (61%) for many non-resident heads of households. The average non-resident angler was 47 years old with an annual family income of $24,550.

If they could not fish for trout, 26% of the groups would return just as often, 40% would return but not as frequently, and 34% would never return to the area. We also asked respondents about the quality of fall fishing in order to obtain specific details about the effect of low dissolved oxygen in the fall. Of the 332 anglers who had fished at Lake Taneycomo in the fall, 17% thought fishing was good, 20% thought fishing was poor, 14% mentioned a dissolved oxygen problem, and 43% had no comment.

We chose four methods to determine the economic value of the Lake Taneycomo fishery to anglers and to the Taney County economy: (1) market value of the fish; (2) summation of gross angler expenditures; (3) income multiplier technique; and (4) the consumer surplus approach. Expenditures of resident and non-resident anglers were combined for methods 2, 3, and 4.

The market value of fish technique is based on the assumption that the value of a fishery equals the value derived by selling the fish in an open market. Crutchfield (1) proposed this technique in the early 1960's. Replacement costs have been established for rainbow trout by the North Central Division of the American Fisheries Society (2). We applied these values to the average trout population in Lake Taneycomo (100,000 fish ranging from 10 to 70 centimeters in total length). The market value is about $230,000.

The use of gross expenditures as a measure of the value of a fishery has been popular in the past because the figures represent what an individual is actually willing to pay for recreation. Our estimate of daily angler expenditures is $11.17 ± $0.84* per person in the Lake Taneycomo area. Annual gross expenditures for anglers totaled $2.7 million. Including other group members, the value is $3.7 million.

The income multiplier technique has been used in a number of situations to calculate net benefits to the area. Net benefits include total direct and indirect (multiplier) income derived from anglers minus the costs of importing goods. On a regional basis, this method takes into account that some money will be exported to purchase goods and pay taxes, while what remains will continue to circulate. Applying multipliers developed for southwestern Missouri, the estimated value of the Lake Taneycomo fishery is $7.2 million.

* This range in values represents the 95% confidence interval.

The consumer surplus approach involves recording the origin and expenses of a random sample of people who use the resource. In theory, the value of the experience is worth at least as much as the expenses incurred by the visitor from the greatest distance, or he would not have made the trip. Beyond this distance, the expense of the trip exceeds the expected benefits and no one attends. We assume that the benefits are the same for everyone, regardless of distance traveled or expense incurred. Within the maximum distance traveled, consumer surplus is the value realized by each person over and above their expenses. Living close to the resource results in a high consumer surplus, and a high ratio of benefits to costs. A model of visitation was constructed based on distance traveled and total population within each of 11 concentric rings around Lake Taneycomo. After a value is determined for each unit of distance traveled, consumer surplus is summed for everyone from areas in which people are drawn to the resource. The consumer surplus was estimated to be $9.2 million for the Lake Taneycomo fishery.

We recommend the consumer surplus approach of the four methods used to valuate the Lake Taneycomo fishery. This method gives the most reliable estimate of direct economic benefits to the area and indirect benefits to anglers and their groups. The market value of fish approach does not take into account the recreational value of the fishing experience. Another problem is that the species and size distribution of fish needed to replace the population may not be available. Gross expenditures represent at best a minimum value for the recreation experience. These data are useful to establish trends or look at specific segments of the area economy. The income multiplier method is an improvement over the use of gross expenditures because it takes into account the circulation of money after it is spent. This technique is appropriate for analysis of net economic benefits to the area.

## ANGLER EFFORT AND SUCCESS

Two types of angler counts were made to meet our objective of estimating angler effort: (1) total counts -- all anglers on Lake Taneycomo at a given time; and (2) partial counts (made twice daily) -- all anglers within a 1.2-km zone of Lake Taneycomo. A positive relationship ($R^2$=0.85) exists between the partial counts and total counts. These counts and the daily pattern of use were the basis of estimating total angler effort. Anglers spent approximately 240,259 days or 1,119,679 hours fishing at Lake Taneycomo from June 1978 through May 1979. About 91% of the effort was for rainbow trout.

Air temperature, an indicator variable for season, was the only variable we tested which was significantly related to angler effort on a weekly basis ($R^2$=0.72). Angler effort increased with increasing temperature. This result was expected because people take family vacations in the summer -- the period of greatest use and highest temperatures. Effort in the spring and fall was

intermediate. Only the dedicated fishermen were present in the winter.

Angler effort is related to angler success on a seasonal basis. Prior to the dissolved oxygen problem, angler success and effort were nearly identical in the spring and fall from 1959 to 1967. Angler effort has increased steadily since 1959, but mean effort in the spring has tripled from 1959-67 to 1968-74, whereas in the fall it has only doubled. The difference is mean angler success. The harvest rate of trout in the spring remained near 0.5 per hour from 1959-67 to 1968-74. However, in the fall, harvest dropped from about 0.5 to 0.3 trout per hour. There is a linear relationship between mean seasonal effort and success ($R^2$=0.78) over a range of harvest rates of 0.21 to 0.80 trout per hour. Any change in the seasonal harvest rate of 0.1 trout per hour results in an increase or decrease in effort of about 20,000 hours during a 3-month period in the fall.

A catch survey was designed to determine angler success at Lake Taneycomo. Clerks interviewed anglers at the completion of their trips on a randomized schedule at the five access points with the greatest use (Fig. 1). Catch and harvest rates of trout for the year, by anglers fishing for trout, were 0.45 and 0.35 per hour, respectively. The total catch was 458,660 trout (76% of the trout stocked), and the harvest was 356,735 trout (59% of the trout stocked). Over half of the trout anglers (59%) caught at least one trout per day, and about 15% harvested a limit of 5 trout.

A number of criteria were established to test the effects of a variety of variables on angler success at Lake Taneycomo. First, the lake was divided into four study areas (Fig. 1). This eliminates the problem of wide ranges in dissolved oxygen and water temperature from one end of the lake to the other, even though measurements were taken hourly. We arbitrarily selected a minimum of 30 anglers who fished at least 120 hours within a given study area to determine angler success on a given day.

A multivariate analysis was conducted to determine which variables affect angler success. Two models were developed -- one when the minimum level of dissolved oxygen was less than 6 mg/l, and one when it was greater than or equal to 6 mg/l. When the minimum daily level of dissolved oxygen is below 6 mg/l, the level of dissolved oxygen, estimated trout population, and water release from Table Rock Dam are significantly related to catch rate ($R^2$=0.56). When the minimum daily level of dissolved oxygen is greater than or equal to 6 mg/l, water release from Table Rock Dam, the estimated trout population, and angler experience are significantly related to catch rate ($R^2$=0.50).

The interpretation, in general, is that an increase in angler success is directly and linearly related to an increase in the minimum daily level of dissolved oxygen when it is below 6 mg/l, or an increase in angler experience when dissolved oxygen exceeds

6 mg/l. A change in dissolved oxygen of 1 mg/l will result in an increase or decrease in catch and harvest rates of about 0.1 trout per hour. Regardless of the level of dissolved oxygen, angler success improves when the trout population is increased by stocking, or when below-average amounts of water are released through Table Rock Dam. About 45,000 trout would need to be stocked in each of the four study areas to raise the mean harvest rate by about 0.1 trout per hour for a 3-month period. A reduction in the water released through Table Rock Dam of at least 3,200 DSF would be needed to have the same effect.

## ECONOMIC IMPACT OF LOW LEVELS OF DISSOLVED OXYGEN ON THE FISHERY

Angler success and effort are related on a seasonal basis. Angler success is affected by minimum levels of dissolved oxygen below 6 mg/l. Therefore, indirectly, the level of dissolved oxygen influences angler effort. To determine the incremental effects of low levels of dissolved oxygen on the fishery, we constructed a simple model. The model takes into account two important factors: (1) the minimum level of dissolved oxygen in each of the four Lake Taneycomo study areas, given a variable amount of dissolved oxygen in the water released from Table Rock Lake; and (2) selection of a typical year with respect to levels of dissolved oxygen and mean daily discharge of water from Table Rock Lake.

Four smooth curves (one for each study area) were fit by eye to represent minimum levels of dissolved oxygen in each study area. The curves represent a typical year with respect to dissolved oxygen and water release from Table Rock Lake. First, the mean value of the minimum level of dissolved oxygen from September to November is calculated for each study area. Then, the mean value of dissolved oxygen is subtracted from 6 mg/l for each study area, and multiplied by the percentage of angler effort in that area. The results are summed to form a weighted average, with the final value representing the average deficit of dissolved oxygen from 6 mg/l over the entire lake. Our estimate of this deficit is 2.1 mg/l.

The seasonal dissolved oxygen deficit can be multiplied by angler effort lost per mg/l yielding an estimate of 42,000 hours of fishing lost (2.1 x 20,000). Since the average day of fishing in the fall is 4.6 hours, a total of 9,130 days of fishing are lost in the fall of a typical year because of low levels of dissolved oxygen. Under a range of different dissolved oxygen conditions, given normal water release patterns (2,500 to 3,000 DSF in the fall), the number of days lost could vary from about 6,800 to 11,000. The value of this recreation lost to anglers and the area economy is currently estimated to be about $350,000 per year based on the consumer surplus approach. Unusually high water releases from Table Rock Lake in the fall will compound the problem and increase the potential value lost to over $500,000.

## FUTURE EVALUATIONS

The information in this report will be finalized by November of 1980 and presented to the Little Rock District of the U.S. Army Corps of Engineers. A study of alternatives for maintaining the level of dissolved oxygen at or near 6 mg/l will be initiated. The Corps will be in a good position to make a decision at Table Rock Dam since the potential benefits, as well as costs, will be identified.

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# LAKE PONTCHARTRAIN WATER QUALITY STUDIES

By

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and

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## INTRODUCTION

### 1. Study Area

Lake Pontchartrain is part of a large estuary in south Louisiana which plays a major role in the economy of the state. It covers approximately 1631 $km^2$ at an average depth of 3.7 m. The lake is subjected to tidal influence primarily through the Rigolets and Chef Menteur Passes which connect it to Lake Borgne which is openly connected to the Gulf Of Mexico. Because of tidal influence, the waters of Lake Pontchartrain exhibit a longitudinal salinity gradient, its waters being essentially fresh at its western boundary and gradually increasing to a maximum average salinity of 5 ppt at its junction with the Rigolets Pass.

### 2. Hurricane Protection Project

The Lake Pontchartrain and Vicinity Hurricane Protection Project consists of a combination of levees, floodwalls, and flood control structures at various locations along the banks of Lakes Pontchartrain and Borgne as well as along the banks of adjacent waterways. The project was authorized by the Flood Control Act of 1965 and federal construction was initiated in May, 1967.

The purpose of the project is to provide protection to the Greater New Orleans Metropolitan Area from possible hurricane flooding. This protection includes floodwalls and levees along the Inner Harbor Navigation Canal and around the areas east of that canal as well as around the Chalmette area, navigable floodgates at Bayous Bienvenue and Dupre, a seawall at Mandeville, and barrier complexes at the tidal connections between Lake Pontchartrain and the Gulf of Mexico: the Rigolets, Chef Menteur Pass, and Seabrook. Also included are improvements to existing protective works such as those between South Point and the Gulf Intracoastal Waterway in the northeastern section of Orleans

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Parish, along the Gulf Intracoastal Waterway, Mississippi River--Gulf Outlet, and a lakefront levee in St. Charles Parish. The construction of the St. Charles lakefront levee has been deferred indefinitely for environmental considerations.

3. Need for Water Quality Monitoring

In the planning, development and operation of Corps of Engineers projects in Lake Pontchartrain, the acquisition and processing of water quality data are essential to quantify existing conditions, forecast future trends and project changes that may come about as a result of the implementation of flood control and navigation projects. The types of data collected and their spatial and temporal distributions are normally dictated by the dynamics of the water body, the nature of the anticipated problems and the types of projects under consideration. Several data collection programs currently in progress in Lake Pontchartrain are described in this paper, each of which has been designed to provide the information required for its specific objective.

4. Objectives of Monitoring Program

The primary objectives of the water quality monitoring programs currently in progress in Lake Pontchartrain are listed below:

a. To observe and predict trends in water quality. A concomitant requirement will be the measurement of baseline water quality levels.

b. To establish a data base for the planning and development of water resources. In operational terms, this means delineation of spatial and temporal distribution of water quality parameters.

c. To furnish data for the evaluation of control and abatement measures.

d. To provide data for use in EIS's and GDM's.

e. To provide data base for the development, calibration, and verification of mathematical models of water quality.

f. To collect data required for other research.

## BASELINE MONITORING

The baseline monitoring network consists of the bi-weekly collection of instrumental readings of basic water quality parameters at approximately 16 stations with a water sample collected at 7 of these stations. This network is supplemented by 5 stations at which daily water samples are collected and analyzed for chloride ion content, and 5 stations at which continuous conductivity recorders have been installed.

### 1. Continuous Recorders

Continuous recorders have been used in the New Orleans District (NOD) to monitor conductivity since 1961. The initial network employed Beckman Model RQ conductivity recorders which use a circular chart driven by mechanical timer motors as the recording mechanism. Conductivity is recorded on the charts in either millimhos/centimeter or salinity in parts per thousand as a function of time. The charts are presently processed by using an optical digitizer to convert the data into digital form for computerization.

These recorders have proven to be quite rugged and field maintenance consists of bi-weekly changing of the charts, periodic replacement of batteries and cleaning of probe and cables. In addition, a platinizing procedure is carried out on the probe's electrodes once each year. The circular chart recorders are being phased out and replaced by water quality monitors manufactured by Ocean Data Equipment Corporation and Martek Instruments. These monitors measure conductivity, temperature, dissolved oxygen and pH, and record these parameters as a function of time on magnetic tape cassettes. These units require more frequent maintenance procedures, especially the dissolved oxygen probe which requires frequent electrolyte and membrane replacement. Real time transmission by means of the GOES satellite has been incorporated at several of these monitoring stations.

### 2. Daily Chloride Observations

At the chloride stations, a water sample is collected daily at 8:00 a.m. by a paid observer. The samples are delivered by NOD personnel to a water quality laboratory and analyzed for chloride content. The water temperature is recorded at the time of collection. Some of these stations have been sampled since 1942 and therefore constitute a valuable data base with a long period of record.

3. Biweekly Instrumental Measurements and Water Samples

Instrumental measurements of conductivity, temperature, dissolved oxygen, and pH are conducted every two weeks using a portable water quality monitoring instrument. The measurements are made from a helicopter that hovers over the sampling site while the instrument probe is lowered below the water surface and the readings are recorded on a data sheet in computer coding sheet format. At a selected number of these stations a water sample is also collected by lowering a plastic container from the helicopter and filling a set of sampling bottles from it. The water samples are preserved in ice until their delivery to the analyzing laboratory. This delivery is accomplished within six hours from the time of sample collection.

4. Data Handling and Dissemination

The results of water sample analysis are automatically edited and entered into the U. S. Geological Survey's Watstore Computer files. The data collected by instrumental readings are edited by NOD's computer and entered into NOD's internal water quality data bank. All data are also entered into the EPA's STORET data system for interagency availability. NOD's internal data bank has the necessary software to retrieve the data in either detailed listing or summarized tabulations or plots. Software is also available to carry out basic statistical analyses.

## SPECIAL STUDIES

Lake Pontchartrain has been the subject of numerous studies conducted by Federal and state agencies as well as local universities. Of special interest in characterizing the quality of the waters in Lake Pontchartrain are the following special studies conducted in connection with the Hurricane Protection Project.

1. Mathematical Modeling by Waterways Experiment Station (WES)

A prototype data acquisition program was conducted in Lake Pontchartrain by WES in cooperation with NOD as a part of the Lake Pontchartrain Hurricane Barrier Project. The data acquisition includes an intensive measurement program of approximately 30 days duration and a one-year measurement program. Data acquired during the 30 day program included:

a. Tidal elevation data (18 gages)

b. Tidal current data (35 meters)

c. 25-hour current data survey

d. Anemometer data

e. Conductivity, temperature, DO, and pH transect data

The one-year program included:

a. Tidal elevation data (18 gages)

b. Tidal current data (14 meters)

c. Anemometer data

The 30-day period extended from September 1978 to October 1978.

The one-year program was initiated in September 1978. The water quality instrument used in this data collection program was a Hydro Lab Water Quality Monitor. The water quality measurements were obtained by traversing predetermined paths across the lake obtaining instrumental readings at periodic intervals. The data so far collected in this study are currently undergoing analysis and review.

2. Ecological Studies by Louisiana State University

A contract was entered into with Louisiana State University to prepare an inventory and analysis of the environmental components in Lake Pontchartrain and its surrounding wetlands. This will provide the base condition with which to compare the after-project condition. This will insure an adequate analysis of the effects of the project on salinity regimes within Lake Pontchartrain and on ingress and egress of marine and estuarine organisms through Chef Menteur and the Rigolets Passes. It will also determine the value of the surrounding marshlands to the life systems within the lake and define the interactions between the lake and marsh and thus the effects of varied land use on both systems. This study will be used in preparing the new Environmental Impact Statement (EIS).

During the data collection phase of this study, conductivity, temperature, turbidity, current speed, and wind direction measurements have been made throughout Lake Pontchartrain.

A second study focusing upon the transport of biota through the passes of Lake Pontchartrain has been recently initiated, during which water samples collected by LSU will be analyzed for nutrients and priority pollutants by the University of New Orleans.

3. Turbulence Measurements

The transport of biota into and out of Lake Pontchartrain through the Rigolets and Chef Menteur Passes is of vital importance to the preservation of existing ecological communities in Lake Pontchartrain. In order to evaluate the effects of turbulence of flow in the passes upon the transport of biota, it is necessary to quantify these turbulence levels by means of field measurements. The New Orleans District has modified a commercially available magnetic water current meter to enable it to detect instantaneous fluctuations in water velocity that can be used to quantify relative levels of turbulence intensity and develop spectral signatures of the turbulent velocities. Field measurements have been made at several cross sections in the Rigolets and Chef Menteur Passes using this instrument and preliminary data evaluation indicates that this technique will provide valuable data to characterize the levels of turbulence existing in these passes. These turbulence measurements will eventually be coupled with water quality parameters, such as dissolved oxygen levels and changes in conductivity, to evaluate the dynamics of the water quality conditions in the Passes of Lake Pontchartrain.

## CONCLUSIONS

The water quality monitoring networks in Lake Pontchartrain have been successful in accomplishing the objectives for which they were designed. The data collected by the baseline monitoring network have resulted in a documented assessment of background water quality conditions in the lake. Periodic review of these data has resulted in improvements to the network by relocating stations that do not show significant variations in water quality to more dynamic locations. In addition, the frequency of water sample collection has been reduced from two to one sample per month as the data collected indicated that the reduction in sampling frequency was justified. The water quality monitoring program in Lake Pontchartrain has shown that frequent data review is essential to the maintenance of an adequate and cost effective water quality sampling network.

# LOST CREEK LAKE
# TURBIDITY STUDY EVALUATION

By

Richard A. Cassidy[1]

## INTRODUCTION

Lost Creek Lake is a Portland District impoundment located in the southern part of Oregon on the Rogue River. It is one of three authorized projects in the Rogue River Basin and was completed in 1977. The other projects include Applegate Lake, which is currently under construction, and the proposed Elk Creek Lake, which is authorized but in an unfunded status. Lost Creek Lake was authorized for flood control, irrigation, municipal and industrial water supply, fish and wildlife enhancement, hydroelectric power generation, water quality and recreation.

The Rogue River was first brought to national attention by Zane Grey in his western novel Rogue River Feud. The river has since become internationally famous for its anadromous fishery. There are approximately one-half million steelhead trout, spring and fall chinook, and coho salmon that annually return to the Rogue River to spawn (J. Athearn, Portland District - personal communication).

Eighty-four miles of the lower Rogue River have been designated "wild and scenic" under the National Wild and Scenic Rivers Act of 1968. It is heavily utilized by salmon fishermen and other outdoor enthusiasts. Approximately 9,000 individuals per year fish the "wild and scenic" reach in private and commercial drift boats and about 40,000 people per year visit in tour boats (D. Farley, U.S. Forest Service - personal communication).

A significant portion of the upper part of the Rogue River Basin consists of the Rogue River National Forest and Crater Lake National Park. Approximately 600,000 visitors per year enter the national park (P. Smith, U.S. Park Service - personal communication).

Because of the national importance of the Rogue River as a natural resource, considerable concern was originally expressed pertaining to the construction of a dam on this river system. The past history of temperature and turbidity problems in the basin was of special concern. The culmination of those concerns was the action taken by the Portland District to incorporate a multilevel withdrawal structure at Lost Creek Lake.

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## MULTILEVEL WITHDRAWAL

Lost Creek Lake is the first project in the Portland District with multilevel withdrawal capability. The 257-foot high intake tower consists of a 30-foot diameter wet well forward of a 28-foot diameter machinery shaft.

Water can be withdrawn from 5 levels within the impoundment. Four tiers consist of three 6 x 15-foot ports at each tier level. A 400-foot long, 12.5-foot diameter low level withdrawal conduit at invert elevation 1595 feet, National Geodetic Vertical Datum, connects to the center port of the lowest tier (1640 feet, NGVD) to form the fifth level of withdrawal.

Any one tier is capable of passing 3000 $ft^3/s$. Withdrawal capacity from all levels at the minimum flood control pool is 9820 $ft^3/s$ or 11,000 $ft^3/s$ at the maximum flood control pool.

Bulkhead gates for operating the ports, regulation outlet and power penstock are controlled by cable and hoisting machinery from the deck. A 16-foot diameter penstock goes 1400 feet from the intake structure to two 24,500 kilowatt Francis turbines in the powerhouse.

The intake tower also has a warm water skimming device to withdraw water from the reservoir surface for the Cole M. Rivers Fish Hatchery via a 30-inch diameter telescoping standpipe. The standpipe entrance is always 5 feet below the surface of the pool. The warm water system is designed to discharge 60 $ft^3/s$ at the minimum flood control pool and 70 $ft^3/s$ at maximum pool.

## WATER QUALITY STUDIES

Water quality studies have been ongoing through the pre-impoundment, closure and post-impoundment periods at the reservoir. Ten sampling stations were established within the impoundment area; inflow stations were established on each of the two major tributaries to the reservoir and one outflow station was established immediately downstream of the project area.

The U.S. Geological Survey was funded to establish and maintain a water quality data collection program at their river flow gaging stations on the two major tributaries and the outflow from Lost Creek Lake. The inflow station on the main stem Rogue River and the outflow station downstream of the dam had a Hach Surface Scatter Turbidimeter and a PS-69 inter-agency sediment sampler. The remotely located inflow sampling station on the South Fork Rogue River was equipped with only the inter-agency sediment sampler. The Portland District also had water quality personnel collect daily grab samples for turbidity and suspended sediment at the main stem inflow station and the downstream station.

## RESULTS

The most significant stream turbidity measured in the upper Rogue River since completion of Lost Creek Lake occurred during the first year of closure. Two storms occurred during the winter of 1977; the first storm was during late November while the second storm occurred in mid-December 1977. Both storms produced inflow turbidity levels of approximately 60 Jackson Turbidity Units (JTU).

During the eight months previous to the first storm, the turbidity level in the reservoir was generally less than 2 JTU. Following the first storm, the Portland District decided not to use the low level withdrawal capability in order to observe how the reservoir would react, hydrodynamically, to the 60 JTU inflowing water. As a result, the turbidity stratification near the dam ranged from less than 5 JTU near the surface to 60 JTU at the reservoir bottom. The most dense portion of the stratification occurred below the withdrawal outlet being used at 1640 feet, NGVD. By early December 1977, reservoir stratification had improved so that the highest turbidity levels in the impoundment were in the 20 to 30 JTU range near the reservoir bottom.

Following the second storm, the Portland District decided to use the low level withdrawal outlet. Inflow turbidity again reached 60 JTU during the second storm. Use of the low level "turbidity outlet" reduced turbidity stratification at the reservoir bottom. Maximum turbidity levels at the dam were between 10 and 20 JTU near the bottom.

It took approximately one month to reduce the turbidity level in Lost Creek Lake to less than 5 JTU throughout most of the water column, and 6 months to reduce the levels to less than 2 JTU.

The Oregon Water Quality Standards (1) for the Rogue River state that "no more than a 10 percent cumulative increase in natural stream turbidities shall be allowed ..." The turbidity data collected both by the U.S. Geological Survey and the Portland District indicate that although the outflow turbidity levels before the two storms (mid-February to mid-November 1977) were usually less than 5 JTU, they did not meet the 10 percent criterion of the State Standards. In addition, although the outflow turbidity following the two storms had dropped to less than 5 JTU approximately 1 month after the second storm, the outflow turbidity did not meet stream standards for 6 months. The outflow turbidity, even then, only met state standards briefly.

The turbidity and suspended sediment data was an important aspect of the total water quality data collection program for the evaluation of the operation of Lost Creek Lake. Because the Portland District had its own backup data collection plan, it was able to perform an inflow, reservoir and outflow turbidity budget for the two storm events. The automatic turbidity and suspended sediment equipment did not properly respond to sampling frequency during the storm events. Without an ongoing grab sample program, little turbidity and suspended sediment data would have been collected.

## CONCLUSION

Evaluation of low level withdrawal to control turbidity at Lost Creek Lake can only be considered preliminary. The data evaluation is considered preliminary because only two storms have produced significantly turbid inflows to the impoundment since closure in 1977. In addition, data collection problems resulted in only daily grab sample analyses during the storm periods. Continuous, automatic sampling was not achieved due to equipment malfunctions.

The preliminary results indicate that multilevel withdrawal at dams, such as at Lost Creek Lake, can make great strides in protecting the natural resources of rivers, such as the Rogue River.

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# WATER QUALITY EVALUATIONS - TENNESSEE-TOMBIGBEE WATERWAY AN OVERVIEW

BY: N. D. McCLURE, IV [1]

The Tennessee-Tombigbee Waterway (Tenn-Tom) is unique in a number of aspects. In addition to its large size - 232 miles long with 10 impoundments; and its cost - approximately 1.8 billion dollars; and its construction period - 15 years; the very purpose of the waterway is unique. The Tenn-Tom provides an alternative transportation mode by connecting two existing waterways - the Tennessee River on the north and the Black Warrior-Tombigbee on the south. Two Corps Districts are involved in the design and construction. Nashville has the Divide Section and Mobile has the Canal and River Sections. As you might imagine, a project of this magnitude involves a number of diverse water quality considerations. Therefore this paper will only provide a broad overview of the type water quality evaluations that have been conducted; are underway; or are planned for the future.

A brief description of the waterway will be helpful in understanding the various types of water quality considerations. Beginning on the north, the Divide Section has a number of interesting features. First there is a 27 mile long cut through the divide separating the Tennessee and the Tombigbee watersheds. This cut involves the disposal of some 150 million cubic yards of material. The cut has a maximum depth of 175 feet and influences the groundwater regimen over approximately 100 square miles. The southern terminus of the Divide Section is the Bay Springs Lock and Dam which has a lift of 84 feet. From a water quality standpoint, the Divide Section involves extensive erosion control measures; the interaction of ground and surface waters; and the transfer of water from the Tennessee River to the Tombigbee Basin. (See Figure 1).

The next element of the waterway is the Canal Section which involves 5 impoundments. It is being constructed utilizing what has been coined the Chain of Lakes Concept. The Canal Section is located on the eastern edge of the floodplain roughly paralleling the Tombigbee River (also called the East Fork). The canal is created by levees and excavation of material from the canal. Only a riverside levee is utilized and the water is impounded against the highground to the east thus creating a series of 5 small lakes. The primary water quality considerations in this section are related to the distribution of flow between the canal and the East Fork to insure a favorable flow regimen in both water bodies.

The River Section involves the transformation of a natural stream into four run-of-the-river impoundments. A number of cutoffs are involved and some 84 million cubic yards of material requires disposal. The four dams offer the opportunity for incremental reaeration. The primary water quality considerations relate to the disposal of the material and the changes in assimilative capacity of the water bodies.

1/ Environmental Engineer, Mobile District

An understanding of the general water quality characteristics of the project is also helpful in describing the water quality evaluations. The Tennessee River water that will be transferred comes from Pickwick Lake. This water is generally of high quality and is very similar to the water in the upper Tombigbee River. However, the Tennessee River is slightly higher in dissolved solids than the upper Tombigbee. Historically, there was a mercury problem in the Tennessee River, but the source was essentially eliminated about 10 years ago and this is no longer considered to be a problem of any magnitude. The groundwater, while varying from aquifer to aquifer, is in general similar in quality to the surface water. Some of the groundwater is somewhat high in iron.

The water quality in the Tombigbee River is influenced by the flow characteristics of the stream and its tributaries as well as by localized point sources of pollution. During periods of extreme low flow the tributaries entering the river from the East contribute practically all of the base flow to the river while those entering from the west carry only the effluents from industrial and municipal sources. Even during normal flows the western tributaries contain higher concentrations of many constituents and exhibit a higher conductivity than the eastern tributaries. Historically, state water quality standards have been violated in the western tributaries during low flow periods. This situation should improve as additional treatment facilities are provided.

With these basic factors in mind we can now begin to describe the water quality evaluations for the Tenn-Tom. The water quality studies are actually a component of the overall continuing environmental studies for the waterway which are being accomplished in three phases. Phase I involved the gathering of existing data and an assessment of the anticipated impacts associated with the development of the waterway. Gaps in the data base were identified for future collections. Preliminary analyses were conducted in the following general areas:

a. Stratification
b. Eutrophication
c. Waste assimilation
d. Reaeration
e. Water transfer

The conclusions from these evaluations were presented in the Environmental Impact Statement (EIS) for the waterway. The adequacy of the EIS was challenged in Court, in 1971, and water quality was one of the issues. The EIS withstood this judicial test.

Phase II of the continuing environmental studies involves the collection of additional data and has the objectives of minimizing adverse environmental impacts and maximizing environmental protection while seeking measures for enhancement. Phase II, which is still ongoing, includes the following general categories of water quality evaluations:

a. Collection of additional baseline data.
b. Screening analyses - particularly for heavy metals and pesticides.
c. Predictive methods - physical and mathematical modeling.
d. Monitoring of construction activities.

Phase III evaluations will involve further monitoring during construction and post impoundment investigations after the waterway is in operation. The continuous water quality monitors that are being installed at the various projects along the waterway constitute an important element in this evaluation effort.

The efforts in pursuit of improved environmental quality have benefited greatly from the guidance provided by the Board of Environmental Consultants. The Board was constituted in 1971, during Phase I of the continuing environmental studies effort and continues to actively function today. The Board represents a vital element in the interdisciplinary approach that is being utilized in the planning and evaluations of the waterway. The Board is comprised of three highly qualified and recognized professionals, each representing a different area of expertise. The members are:

1. Dean Gerald J. McLindon
   (Environmental Planner and Landscape Architect)
   Dean of the School of Environmental Design
   Louisiana State University

2. Dr. Philip E. LaMoreaux
   (International Consultant in the Field of Hydrogeology)
   Professor, University of Alabama
   State Geologist and State Oil and Gas Supervisor (Retired)

3. Dr. Stanley I. Auerbach
   (Ecologist)
   Director, Environmental Sciences Division
   Oak Ridge National Laboratory (DOE)

The Board meets quarterly and has contributed significantly in reviewing the water quality evaluations and suggesting refinements or additional studies. Their input helps to keep the water quality efforts in perspective and assures that sufficient data are gathered to support and complement other environmental study efforts.

For the purpose of describing the various water quality investigations and evaluations for the Tenn-Tom, they are divided into three broad categories. Of course the individual studies involve varying levels of sophistication

and effort. Only a very brief description is presented but a list of references is provided if you have interest in any particular study effort.

The first category involves study efforts that can be classified as establishing long term baseline data. A program for collecting these data was developed based on the findings in Phase I, in coordination with the U.S. Geological Survey (USGS). The surface water stations were selected to coincide with established USGS stations where possible. This had two positive factors: (1) A long term stream flow record was usually available, and (2) Additional historic background water quality data were sometimes available. The parameters and the frequency of measurement were selected after consideration of factors such as anticipated impacts, areas of potential or existing water quality problems or concerns, and an examination of the adequacy of existing data base.

This category also includes groundwater quality. A series of observation wells had been established along representative transects along the waterway in order to gather data on the effects of the waterway on the groundwater regimen. Water quality data are being collected from a number of these wells in the various aquifers that could possibly be influenced.

The second category of water quality evaluations is designated model studies. The most elaborate model studies were associated with the Divide Section and the Bay Springs impoundment. It was recognized in the EIS that this lake would undergo the phenomenon of thermal stratification and that special measures might be necessary in order to assure adequate dissolved oxygen and a desirable temperature regimen in the release waters. The studies were conducted by the Waterways Experiment Station (WES). An extensive physical model of the entire Divide Section was constructed to gain knowledge of the flow dynamics that could be expected under the unique situation that would exist. The information gained from the physical model was then used to calibrate and adapt a reservoir numerical model, WESTEX. The results are reported in a WES publication entitled "Bay Springs Lake Water Quality Study."

The predicted temperature regimen of the release waters from Bay Springs, while in the range satisfactory for supporting the propagation of a warm water fishery, did lag the natural temperature pattern exhibited by the stream. Since this lag could conceivably influence spawning habits an extension of the Bay Springs study in the form of a temperature simulation study was conducted to better define the situation. This study indicated that atmospheric conditions and local inflows would drive the temperature pattern toward natural conditions and the waters would support a warm water fishery.

Another modeling effort that was conducted early in Phase I of the environmental studies related to the change in waste assimilative capacity in the River Section and the effects of the transfer of water from the Tennessee River on the assimilative capacity during the critical low flow periods. This study, which involved the limited application of a version of the classical Streeter-Phelps method to selected situations, indicated that the increased flow from transfer would more than compensate for the loss in the reoxygenation capacity. This was later substantiated with a more

sophisticated study conducted by Meta Systems, Inc., under contract to the Tombigbee River Valley Water Management District, the Mississippi project sponsor, and the State of Alabama. These studies involved the application of an adapted version of the Qual-II computer simulation model developed by the Enviornmental Protection Agency.

As mentioned previously the dams in the River Section present opportunities for incremental reaeration which might be anological to a periodic transfusion which supplements the natural processes. The reaeration potential of the dams was analyzed utilizing mathematical approaches developed by Dr. Holler of the South Atlantic Division and some experimental data from EPA.

The third category of water quality studies is somewhat of a catchall and is simply called Special Studies. The largest component of this category is the construction monitoring efforts. Elaborate and innovative measures have been incorporated into the project design in the interest of protecting water quality. In an effort to insure that water quality standards and objectives are met and/or exceeded, and to provide data for improving the control systems, surveillance activities have been undertaken. Extensive long term studies are being conducted in the Divide Section utilizing both continuous water quality monitors and grab samples. In the River Section special studies have been conducted to evaluate the effectiveness of the dredge disposal concept adopted for this portion of the waterway.

Also included in the special studies category are the evaluations required under the guidelines developed pursuant to Section 404(b) of PL 92-500, as amended by the Clean Water Act of 1977. Screening evaluations for exotics such as heavy metals and pesticides were useful in performing these evaluations and in designating the location of disposal sites.

Another study element in the special studies category is the investigation currently underway by WES on the cutoffs and severed bendways that will be created by the waterway. This study is being accomplished under the auspicies of the Environmental and Water Quality Operational Studies (EWQOS). The cutoff bendways, or oxbows, are recognized as valuable resources which have a natural tendency to lose value through the siltation processes. The WES study is designed to evaluate these resources; to seek measures to prolong the life of these resources; and to enhance their contribution to the overall ecosystem.

The Divide Section intercepts a number of aquifers and dewatering wells have been incorporated to assist in removing excess water so the massive excavation can be accomplished. Another special study that was conducted involved an analysis of the quality of the water discharged from the dewatering wells. The quantity of the water involved is small when compared to the natural stream flows and the study indicated that the constituents of the groundwater were very similar to the surface water. Iron concentrations are higher in some of the aquifers, but this does not create a significant problem.

Another study effort involves the establishment of the water quality characteristics of some small tributaries in the Divide Section under low flow conditions. This investigation will be utilized during Phase III in an attempt to analyze any influence on water quality that the interactions between the ground and surface waters may have on these small tributaries.

A rather interesting special analysis involved the establishment of an "artificial" or "reproduced" ambient condition as a basis for comparison, so evaluations relating to any alterations to the normally expected turbidity conditions in the Divide Section could be made. This analysis was required because the Divide Cut so alters the natural flow situations that ambient conditions no longer exist. A statistical approach utilizing preconstruction data was used in this effort.

A large amount of water quality data has been collected in support of the studies enumerated above. These data have been published periodically as part of Supplemental Environmental Reports which have been issued as part of the overall environmental studies process. The data are also being placed in either STORET or WATSTOR data banks and are available in the USGS open files. These data have been utilized by others for various types of investigations, particularly those involving potential development along the waterway.

Since the minimization of adverse impacts and improvement of environmental quality are recognized objectives of the overall continuing environmental studies it is appropriate to briefly describe some of the measures that have been incorporated in the interest of good water quality. The erosion control measures in the Divide Section involves a wide variety of approaches; some are temporary while others are permanent in nature. The measures include water diversion, revegetation, sediment ponds, check dams, terraces, control structures and the use of chemical floculants to mention a few.

In the River Section the two celled disposal sites have proved to be effective in controlling turbidity. These disposal sites were acquired in fee simple and were made large enough to accommodate 50 years of maintenance material, thus alleviating a problem that must be faced on a number of existing navigation projects. These sites include buffer strips to screen the disposal area and to provide a transition zone between the aquatic community and the site.

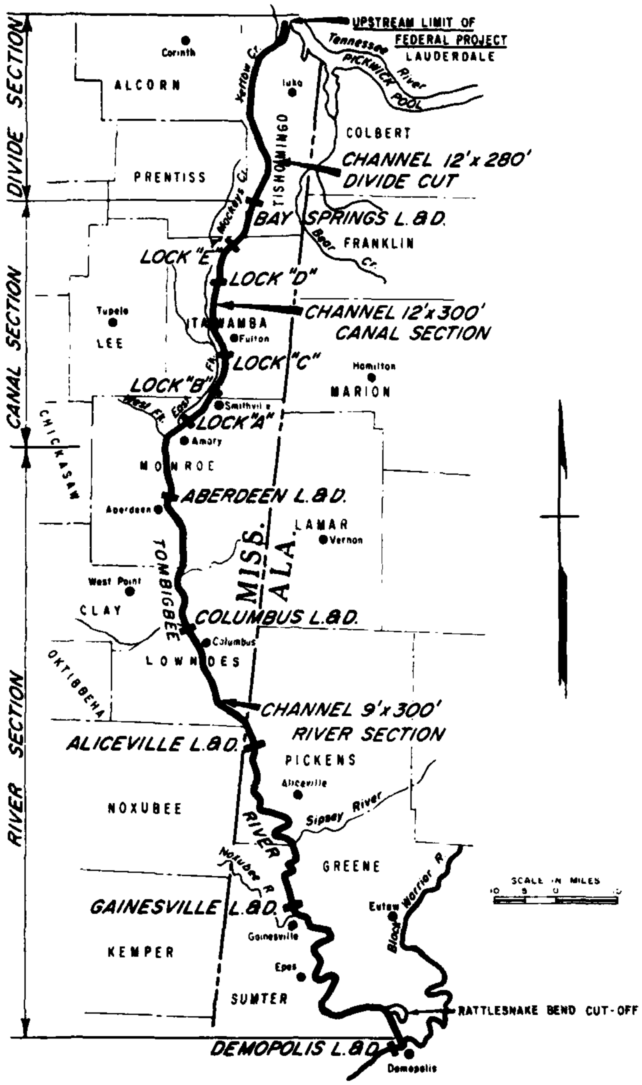
The Bay Springs model studies indicated that some high natural topography in the vicinity of the lock would function as a broad crested weir and in effect, skim the higher quality water from the upper levels of the reservoir for release downstream. In addition, a minimum flow outlet has been incorporated into the dam to insure that releases can be made even if the lock is out of operation.

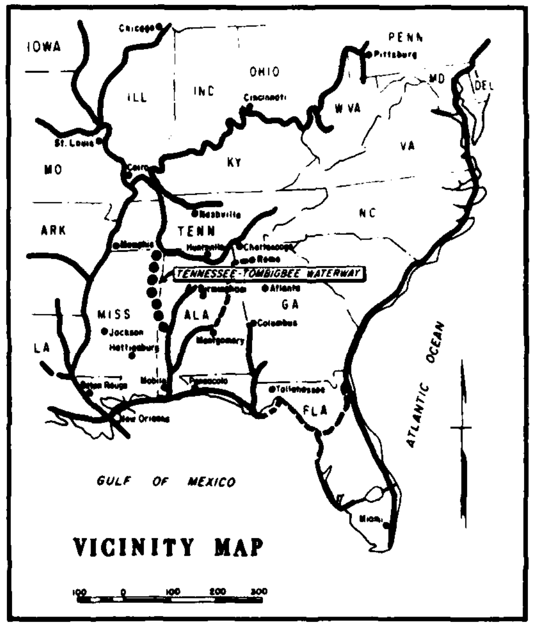
In the Canal Section three special types of hydraulic structures have been incorporated into the plan in the interest of water quality. Grade stabilization structures are provided to control erosion and provide reaeration. Bypass structures are provided to insure that adequate flow is maintained down the navigation canal and minimum flow structures are provided to insure proper flow conditions in the East Fork as well as to preserve the integrity of the wetland resources of the floodplain.

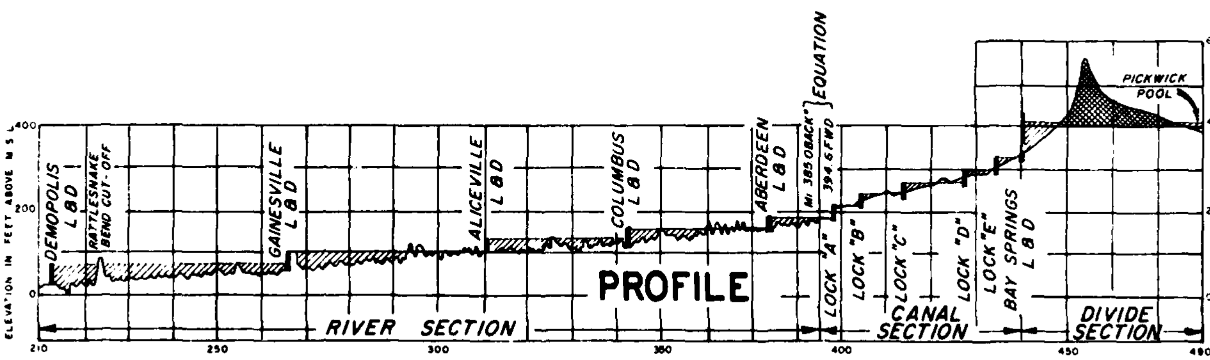
Special provisions have also been incorporated in the River Section to insure that the minimum flows in this portion of the waterway are not interrupted. In this regard each of the four dams are provided with either a minimum flow structure or a section of fixed crest spillway. An added innovation has been incorporated into the fixed crest spillways. The Gainesville Spillway has an aeration ramp to promote the reoxygenation process while the Aliceville Spillway has a special flip bucket designed for the same purpose.

The water quality evaluations for the Tenn-Tom have been underway for almost ten years and will continue for a number of more years. These evaluations have involved diversified and complex considerations and even involved some areas that might be called unique. For a project of this nature the overall evaluation program must be flexible and in the case of the Tenn-Tom the evaluations are still evolving. Coordination, consultation and the implementation of a fully interdisciplinary approach are all vital ingredients to a successful evaluation program.

The overall expectations for the water quality in the Tenn-Tom can be "bottom lined" as - good water quality that meets or exceeds state standards will exist. On the surface this might appear optimistic, however, it is based on a number of supportive factors. Included are the effectiveness of the control measures incorporated during construction; the special water quality features designed into the project; the interdisciplinary approach that was utilized; and the guidance provided by the Board of Environmental Consultants. In addition, improvements in water pollution control and abatement can be expected as the provisions of the Water Pollution Control Act, PL 92-500 and its latest amendments, the Clean Water Act of 1977, are brought to fruition. And finally the attitudes, concerns and awareness exhibited by the locals offer encouragement. Their efforts are reinforced by comprehensive and innovative planning mechanisms such as the Congressionally mandated and Federally funded Tennessee-Tombigbee Corridor Study which is designed to assist the locals in preparing for the waterway and insuring that good water quality will exist. It is believed that the future will hold that the Tenn-Tom serves as example which supports the adage - "Good engineering results in a better environment."




# TENNESSEE-TOMBIGBEE WATERWAY, ALA. & MISS.

U.S. ARMY ENGINEER DISTRICT, MOBILE
CORPS OF ENGINEERS
MOBILE, ALA

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KISSIMMEE RIVER STUDY

BY

JOHN DRYDEN [1]

To introduce a discussion of the Kissimmee River Study it is helpful to develop an understanding of some of the unique features of this study. The idea for this study was fostered by a belief among many State entities that deteriorating water quality in the Kissimmee Valley and Taylor Creek-Nubbin Slough Basin was leading to accelerated eutrophication of Lake Okeechobee. Couple this belief with the State's suggested alternatives which would negate the Kissimmee River Flood Control and Navigation Project purposes and the emergence of the Kissimmee River restoration theme is evident.

To develop an understanding of what motivated the congressional resolution for the Kissimmee River study, the historical developments in the basin must first be looked at. The history of man's serious influence on the Kissimmee River begins with the Swamp and Overflowed Lands Act of 1850. This act transferred ownership of vast acreages of Florida wetlands from the Federal government to the State. By the late 1800's, these lands had become an important form of currency used by the State to encourage development.

The Kissimmee River Basin drainage area is 3,013 square miles in south central Florida and is adjoined on the east by the Taylor Creek-Nubbin Slough Basin which is about 200 square miles in size. Both of these basins are tributary to Lake Okeechobee, supplying a substantial portion of the total inflow to Lake Okeechobee.

Hamilton Disston is an important figure in the early development of the Kissimmee Basin. Disston purchased millions of acres and was to receive one-half of all the wetlands he could reclaim. To enhance drainage and navigation, Disston began connecting lakes in the Kissimmee Basin with a series of canals and excavated the first Caloosahatchee Canal. Disston also intended to dig a canal from Lake Kissimmee to Lake Okeechobee, but his death prevented him from doing so.

In the first half of the 20th century, hurricane floods were perhaps the most important part of the Kissimmee River story. The storms of 1926 and 1928 killed approximately 3,000 people. This loss of life led to increased pressures to alter the natural systems of south Florida. Late-season hurricane rains of 1947 and 1948 left much of the Kissimmee River Basin under water for extended periods of time. Pressures to maximize drainage from the basin peaked with these late 1940's storms.

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The Federal government responded to increased public demand in 1948 by authorization of the Central and Southern Florida Flood Control Project, a massive undertaking which included Disston's original idea of channelizing the Kissimmee River to provide rapid drainage of developed and developing areas in the Upper Kissimmee River Basin. The work was to be done by the U.S. Army Corps of Engineers, but a local sponsor was needed. So, in 1949 the Florida legislature created the Central and Southern Florida Flood Control District to act as local sponsor for the project.

In 1954, Congress specifically authorized the channelization of the Kissimmee River. Construction of the Kissimmee Canal, termed C-38, began in 1962 and was completed in 1971 at a cost of nearly 24 million dollars. The channelized Kissimmee River is the largest of the connecting canals between the lakes of the Kissimmee-Okeechobee watershed. The natural Kissimmee River meandered for nearly 100 miles between Lake Kissimmee and Lake Okeechobee. The canal is about half that length and is divided into five sections by a series of six control structures which drop water levels from about 50 feet msl to 17 feet msl at Lake Okeechobee.

Another aspect of the Federal-State partnership that developed during this period involved activities in the Taylor Creek watershed by the U.S. Department of Agriculture's Soil Conservation Service (SCS). At the request of local government, the SCS channelized major streams in the basin as part of a small watershed project. Subsequently, the Corps of Engineers in 1973 combined Taylor Creek-Nubbin Slough and several other tributaries into one basin with a common discharge into Lake Okeechobee.

Just as extreme floods were associated with the beginnings of the flood control project, the extreme drought in 1971 was associated with completion of the Kissimmee River channelization and the Taylor Creek-Nubbin Slough alterations. This drought occurred at the time when public awareness of environmental problems was increasing. This awareness resulted in the adoption of several landmark pieces of environmental legislation by both Federal and State governments.

Some of the more important Federal legislation includes the Water Quality Act, the Clean Water Restoration Act, NEPA, and the Water Pollution Control Act Amendments.

The key State legislation was an outgrowth of the 1971 "Governor's Conference on Water Management in South Florida," a conference attended by water resources experts. The consensus from this conference was that water quality was steadily deteriorating in practically all aquatic systems in south Florida, and that water quantity was not being effectively managed to assure a minimum adequate supply in extended periods of drought. Conference participants recommended that the lakes and marshes of the Kissimmee River Basin should be restored to their historic conditions and levels to the greatest extent possible, so that the quality of water entering Lake Okeechobee could be improved.

Participants in these early conferences and subsequent legislation recommended that fish and wildlife resources should be restored, and that contamination of surface water by pastured livestock must be reduced.

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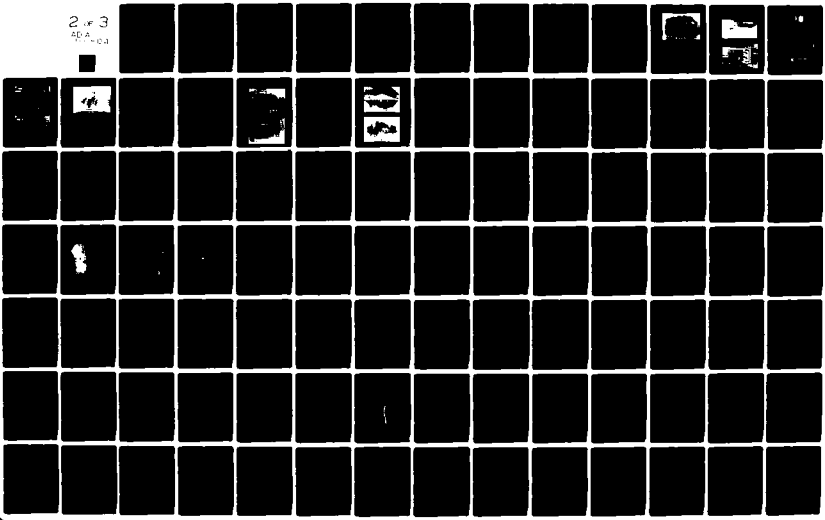

State government's interest in the Kissimmee River Basin intensified. At a December 1972 meeting of the Governor and Cabinet, the Central and Southern Florida Flood Control District presented study results which proposed reflooding part of the Kissimmee River floodplain by raising water levels behind the control structures in C-38.

During 1973-1976 several other independent studies (including the special project to prevent the eutrophication of Lake Okeechobee) concluded that the Lower Kissimmee River Valley and the Taylor Creek-Nubbin Slough Basin together contribute tremendous amounts of critical nutrients to Lake Okeechobee. Overfertilization as a result of man's activities leads to undesirable conditions in lakes and streams. Land use and drainage practices within the two basins significantly increase the amounts of nutrients ultimately entering Lake Okeechobee. The results of these studies led the 1976 Florida Legislature to create the Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin. The 1976 legislation directed the Council to develop measures to restore the water quality of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin. Restoration of natural changes in water levels, recreation of conditions favorable to wetlands and wildlife, removal of threats to agriculture, and protection of presently developed areas from flood were all addressed in the Act.

As the Coordinating Council's planning gained momentum, the proposed alternatives imposed such major modifications to the existing project that congressional approval was required. The Governor and the Cabinet adopted a State resolution on 20 September 1977 requesting a study, and finally, a resolution that authorized a survey review of the Kissimmee River Valley and the Taylor Creek-Nubbin Slough Basin was adopted by the U.S. Congress, House of Representatives, Committee on Public Works and Transportation and the U.S. Senate Committee on Environment and Public Works on 25 April 1978. The resolutions direct us to determine if modifications of the authorized plan, most of which has already been constructed, are advisable at this time with respect to questions of the following:

a. Quality of water entering the Kissimmee River and Taylor Creek-Nubbin Slough and Lake Okeechobee

b. Flood control

c. Recreation

d. Navigation

e. Loss of fish and wildlife resources

f. Other current and foreseeable environmental problems, and the

g. Loss of environmental amenities in those areas.

The resolutions also direct us to consider alternatives of restoration of all or parts of the Kissimmee River below Lake Kissimmee and of the Taylor Creek-Nubbin Slough Basin. With this Congressional authorization and subsequent funding the study was initiated in September 1978. Stage I studies have been concluded with the completion of the reconnaissance report in September 1979.

During this first stage of the study, considerable importance was placed on public involvement to obtain the opinions and ideas of local, State, and other Federal agencies regarding the problems and needs of the Kissimmee area. The first actions included several meetings last fall with interested Federal and State agencies having specialized knowledge in fish and wildlife studies, and economic base studies. In March, the public involvement effort was expanded through a contract with the State's Kissimmee Coordinating Council staff. The contract required extensive workshop efforts in 12 cities in and surrounding the study area. The public involvement program also included the formation of an Assistance Committee which is providing technical guidance from a cross section of special interest groups. This committee is expected to be very helpful particularly in the water quality studies and, in fact, a subcommittee for scoping the water quality modeling effort was recently established.

Another interesting result of the stage I public involvement efforts is a shift away from concern about water quality in the Kissimmee River. The results of many studies conclude that the Kissimmee River is the largest contributor of nutrients to Lake Okeechobee only because it has, by far, the largest contributing volume. In fact, the Kissimmee Coordinating Council Staff Director at one public meeting stated that water discharged from Lake Kissimmee was "better than rain water." Of course, Taylor Creek-Nubbin Slough Basin continues to be recognized as the major contributor of nutrients to Lake Okeechobee.

These initial public involvement efforts have resulted in the preparation of a comprehensive list of public concerns which represents the needs of the basin. This list illustrates the shift away from a singular concern of water quality.

- Stabilized water levels
- Loss of wetlands
- Loss of fish and wildlife resources
- Degraded water quality
- Flood damage potential
- Loss of recreational and esthetic values
- Potential inadequate water supply
- Potential loss of navigation capabilities

Several new planning techniques are being employed in this study. In order to accurately assess the impacts of each of the alternatives, spatial analysis methodology, or SAM, will be used for data management. This will enable the comparison of environmental, economic, and hydraulic consequences for each alternative. The use of SAM, which is simply a systematic method of storing and retrieving data, will be particularly useful in the Kissimmee study for two reasons: (1) because of the tremendously large amount of data (i.e., 3,000-square-mile study area), and (2) because of the anticipated large number of alternatives which will have to be analyzed.

There have been notable improvements in HEP technical procedures through the added capability of separate habitat evaluations by species and through the requirement that HEP users obtain land use projections from the lead planning agency. The separate habitat evaluation of 25 selected species in the Kissimmee area allows planners to assess the impact for each specie or group of species and it provides a means for determining how many habitat units and/or acres of wetland are needed.

The ongoing environmental studies also include water quality analysis efforts. The initial literature research revealed a number of comprehensive water quality studies. Early conclusions are that adequate water quality data already exist for the Kissimmee study. The problem now is essentially one of compiling all data and then developing a predictive model to be used in analyzing alternative plans. In this regard it is fortunate to have several water quality models which were recently developed for the Kissimmee Basin. Of particular interest is a model developed in 1976 by Huber and Heaney. Their water quality model takes a nontraditional approach which emphasizes linkage mechanisms which relate land use and drainage conditions to resulting hydrologic and water quality responses in the watershed. A drainage density index in the Kissimmee Valley is directly related to the average length of overland flow, soil moisture storage capacity, and detention times. In this respect, the index serves as an indicator of transport of runoff and nutrients for a particular land use type. As mentioned earlier, a recently established subcommittee will serve an important function of assisting in review of existing models and in scoping the water quality modeling contract.

Given the above discussions it is now appropriate to further explain the uniqueness of this study. First, the study is somewhat precedent setting for Corps G.I. studies by considering restoration at the expense of inducing or incurring additional flood damage or reduction of navigation capabilities. The study is technically not a mitigation effort but rather a new study effort with all the ingredients of mitigation.

Second, the application of principles and standards, particularly the net NED benefits values, determination of base year, and classification of structural and nonstructural measures have been cumbersome for a project oriented toward "environmental restoration." However, recent guidance on net benefits rules now alleviates some problems in developing EQ plans.

Finally, the atmosphere of intense State interest and the high visibility at both State and Federal levels make the study subject to considerable political pressures.

In summary, the Kissimmee River study offers an excellent opportunity for innovative and new planning techniques, especially for environmental enhancement. Selection of a recommended plan will be based on subjective, as well as objective, comparisons of intangible environmental considerations and economic considerations.

ENVIRONMENTAL ASPECTS OF RESERVOIR RELEASES

George M. Strain, P.E. [1]

## INTRODUCTION

When a reservoir is proposed on a major stream in the Southeastern United States, the environmental effects of the proposed hydrologic modification are coming under greater scrutiny because of concerns which have developed at existing impoundments. In addition to the obvious environmental impacts associated with reservoirs such as inundating wildlife habitat and forrested areas, considerable concern is being expressed for the more subtle downstream impacts. The current development and implementation of Statewide water quality management plans will place a greater emphasis on non-point sources. It is envisioned that greater emphasis will be placed on the environmental aspects of existing and proposed hydrologic modifications. The primary purpose of this paper is to discuss the environmental concerns as related to the releases from Corps of Engineers' reservoirs in the Southeastern United States.

## CATEGORIES OF CONCERN

Environmental concerns associated with the releases from Corps of Engineers' reservoirs in the Southeast can generally be categorized into: (1) hydrologic flow regime changes, and (2) water quality aspects. This paper will briefly discuss the first category in a general way and then elaborate on the water quality aspects. This approach is taken in order to emphasize the need for comprehensive environmental consideration of the conditions at the project in lieu of merely pursuing water quality standards for standard's sake.

## HYDROLOGIC FLOW REGIME CHANGES

Downstream hydrologic flow regime changes caused by reservoirs are significantly affected by the project purposes. The vast majority of the Corps' reservoirs in the Southeast are multipurpose. Conflicts arise concerning maintaining a desirable pool for recreation in lieu of maintaining a minimum continuous flow downstream. Further conflicts exist between operation of a reservoir project for peaking hydropower where the vast majority of the water is released during a short period of the day in lieu of maintaining a higher minimum flow. A reduction of the minimum flow, or an increase in frequency of minimum flows below natural levels causes concern for the fishery habitat and the riffle-pool relationship. Furthermore, there has been a concern expressed for the maintenance of at least the natural minimum flows for the dilution and assimilation of treated wastewater discharges. As the design of wastewater treatment facilities for the maintenance of applicable water quality standards is generally based on the ten-year, seven-day low flow ($Q_{7-10}$), concern is being expressed when the minimum releases from reservoirs is less than the $Q_{7-10}$. In some

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cases due to socio-economic pressures for growth and development, proposals for minimum releases greater than the $Q_{7-10}$ are arising. This aspect emphasizes the relationship between water quantity and water quality. Another concern relating to minimum flows involves the need to seasonally increase the minimum flows in specific cases for the anadromous fish.

In regards to a reduction in high flows which are normally associated with the flood control operation of a reservoir, concerns have been expressed for the reduction of inundation of the downstream riverine swamps and subsequently the effects on the wetland vegetation, wildlife habitat, and water quality.

Associated with the pulsating flows from hydropower plants operation for peaking purposes, which vary by more than an order of magnitude, concern has been expressed for the accompanying scouring and erosion action of the silts and the subsequent increased turbidities downstream.

## WATER QUALITY ASPECTS OF RELEASES

The water quality of the release water from Corps of Engineers' deep impoundments in the Southeastern United States is an item of considerable concern. Anoxic conditions in the hypolimnion of these reservoirs combined with low level outlets seasonally produce release water of reduced quality. Normally the water entering these reservoirs is of a high quality. It is generally accepted that the seasonal anoxic condition in the hypolimnion results from the primary production (algal growth) created within the warm epilimnetic waters of the reservoir dropping into the stagnant hypolimnion during periods of thermal stratification. The epilimnetic waters of reservoirs in the southeast commonly approach 30°C. The primary concern for the water quality of the release water from Corps' reservoirs in the Southeast has been related to the parameters of dissolved oxygen, or conditions resulting from the lack thereof, and temperature.

The South Atlantic Division of the Corps of Engineers is currently conducting environmental evaluations of the releases from all of the deep reservoirs within the division. Based on preliminary results of these evaluations, it appears that the releases from seven Corps of Engineers' reservoirs in the Southeast are periodically not in accordance with prescribed water quality standards for dissolved oxygen. These same projects have also generally impacted the natural stream temperature and, in several cases, created conditions where successful trout stocking has been established.

These seven reservoirs are relatively large for the Southeastern United States and range in storage at normal summer pool from about 367,000 acre-ft. to 2,500,000 acre-ft. Maximum depths at normal summer pool vary from 80 feet to 185 feet. Hydropower peaking flows range from 8,000 cfs to 35,000 cfs with a large portion of the total volume of water released during a relatively short period of the day. The depths of the centerline of the intakes to the main turbines for all seven projects are at least 70 feet below the surface and within the hypolimnetic zone. In some cases, the service turbines which provide the minimum flow downstream withdraw from different depths than the main turbines which result in different qualities of the release water. In general, the service units release from higher in the pool and provide better water quality during low flows. This is the case at Allatoona, West Point, and John H. Kerr. However, the case at Buford Dam where the intakes for the

TABLE 1

PROJECT CHARACTERISTICS

| Project | Normal Summer Reservoir Storage, Acre-Ft. | Max. Normal Depth Ft. | Normal Peaking Power Flows CFS | Min. Flows CFS | No. & Size of Hydro-power Units | Depth of Centerline of Intakes for Main & Service Turbines/Ft. | Size Penstocks Ft. |
|---|---|---|---|---|---|---|---|
| Allatoona | 367,470 | 140 | 8,000 | 200 | 2 @36,000 kw<br>1 @ 2,000 kw | 80 Main<br>55 Service | 20 Main<br>5 Service |
| Buford | 1,917,000 | 152 | 8,000 | 550 | 2 @40,000 kw<br>1 @ 6,000 kw | 138 Main<br>138 Service | 22 Main<br>4.5 Service |
| Clark Hill | 2,510,000 | 140 | 27,000 | 5800 | 7 @40,000 kw<br>2 @ 1,000 kw | 76 Main | 20 Main<br>4.5 Service |
| John H. Kerr | 1,472,300 | 130 | 35,000 | * | 6 @32,000 kw<br>1 @12,000 kw<br>2 @ 1,000 kw | 71 Main<br>54 Service<br>46 Service | 24 Main<br>15.5 Service<br>5.5 Service |
| Hartwell | 2,549,600 | 185 | 25,000 | * | 4 @66,000 kw | 105 Main<br>No Service | 24 Main |
| West Point | 604,500 | 80 | 18,000 | 675 | 2 @35,000 kw<br>1 @ 3,375 kw | 74 Main<br>Adjustable Service ** | None |
| Walter F. George | 934,400 | 94 | 27,000 | * | 4 @32,500 kw | 88 Main<br>No Service | None |

*No established requirement for minimum flow
**Adjustable skimmer weir

TABLE 2

| PROJECT | Average Number of Days Per Year Dissolved Oxygen in the Releases is Within Specific Ranges 6-5 | 5-4 | 4-3 | 3-2 | 2-1 | 1-0 | TOTAL | Miles of River Downstream To Reaerate to Water Quality Standards for Most Severe Case High Flow | Low Flow |
|---|---|---|---|---|---|---|---|---|---|
| Allatoona | -- | 24 | 23 | 70 | 0 | 0 | 117 | 4.1 | 2.1 |
| Buford* | 27 | 26 | 26 | 26 | 27 | 48 | 180 | 9.5 | 5.5 |
| Clark Hill | -- | 30 | 50 | 28 | 0 | 0 | 108 | 15 | 15 |
| John H. Kerr | -- | 20 | 25 | 15 | 40 | 10 | 110 | 15 | *** |
| Hartwell* | 25 | 20 | 20 | 25 | 20 | 10 | 120 | 5 | *** |
| West Point | -- | 41 | 52 | 45 | 0 | 0 | 138 | 13** | 15** |
| Walter F. George | -- | 21 | 23 | 21 | 69 | 0 | 134 | 27** | *** |

*Designated trout stream with a water quality standard of 6.0 mg/l
**Based on theoretical $K_2$ values; data collection efforts are planned
***No established requirement for minimum flow

main and service units are at the same elevation provides poorer quality water at low flow. Table 1 provides basic information in regards to these seven projects.

All seven of these projects release the vast majority of their water through hydropower units and create a total capacity of 1,100 megawatts. The hydraulic head is used to create electricity and is not available for reaeration. This demonstrates a direct conflict between energy and environmental concerns. None of these seven projects have a capability for selective withdrawal, or other water quality control devices with the exception of West Point and Allatoona Reservoirs. An adjustable skimmer weir which allows for releases from the upper layers of the lake is provided on the service unit at West Point. In addition, a portion of the construction cofferdam was left in place in front of the main hydropower units at West Point to act as a skimmer weir. This effort has only been partially successful because the coffer dam was breached. Destratification equipment which was installed for test purposes in 1969 at Allatoona has continued to be operated after completing the test at reduced efficiencies.

Table 2 shows the average number of days per year the dissolved oxygen concentration of the releases is below prescribed water quality standards and the maximum number of miles required to reaerate to the prescribed water quality standards. In some cases, as noted, these distances are based on theoretical $K_2$ values calculated according to Tsivoglou's method. The average number of days in Table 2 represents only two years of data in some cases whereas in other cases represents seven years of data from continuous electronic water quality monitors. It should be noted from Tables 1 and 2 that the minimum value of dissolved oxygen in the releases is variable and dependent on the depth of the outlet works. Furthermore, the duration of the low dissolved oxygen levels generally occurs for four to six months per year. Natural reaeration of the releases is generally rapid except in cases where the release enters a downstream impoundment where reaeration characteristics are low. The effect on the downstream impoundment appears to depend on whether it is a deep downstream storage reservoir where the releases will plunge into the hypolimnetic waters seeking equal density water or a shallow run of the river reservoir.

Figure 1 demonstrates the seasonal variation of the average daily dissolved oxygen values of the release waters from Buford Dam in 1972. The actual data shows a rather large variation in average daily dissolved oxygen values during the period of minimum values. This is due to the variation in the operational scheme (flows) and the significant impact of flows on dissolved oxygen. The lowest average daily dissolved oxygen values are reported on weekends when a continuous minimum flow is maintained. The general shape of this curve is characteristic of the dissolved oxygen in the releases from the other reservoir projects discussed above, however, the rate of seasonal deoxygenation (slope of descending portion), the minimum values, and the rate of seasonal reoxygenation (slope of ascending portion) are variable. Table 3 contains values for the average seasonal deoxygenation and reoxygenation rate by project. The range of the average rate of seasonal deoxygenation is relatively small and between 0.04 and 0.11 mg/l-day. The rates for seasonal reoxygenation are generally higher and lie between 0.06 and 0.25 mg/l-day. The higher value for seasonal reoxygenation of 0.25 mg/l-day is observed at Buford Dam where the intake is the lowest, lake is relatively deep, the ratio of storage to outflows is higher, and other factors characteristic of strong thermal stratification are present.

TABLE 3

| Project | Seasonal Average Deoxygenation Rate mg/l-day | Seasonal Average Reoxygenation Rate mg/l-day |
|---|---|---|
| Allatoona | 0.07 | 0.07 |
| Buford | 0.06 | 0.25 |
| Clark Hill | 0.04 | 0.17 |
| John H. Kerr | 0.09 | 0.11 |
| Hartwell | 0.11 | 0.17 |
| West Point | 0.04 | 0.06 |
| Walter F. George | 0.06 | 0.08 |

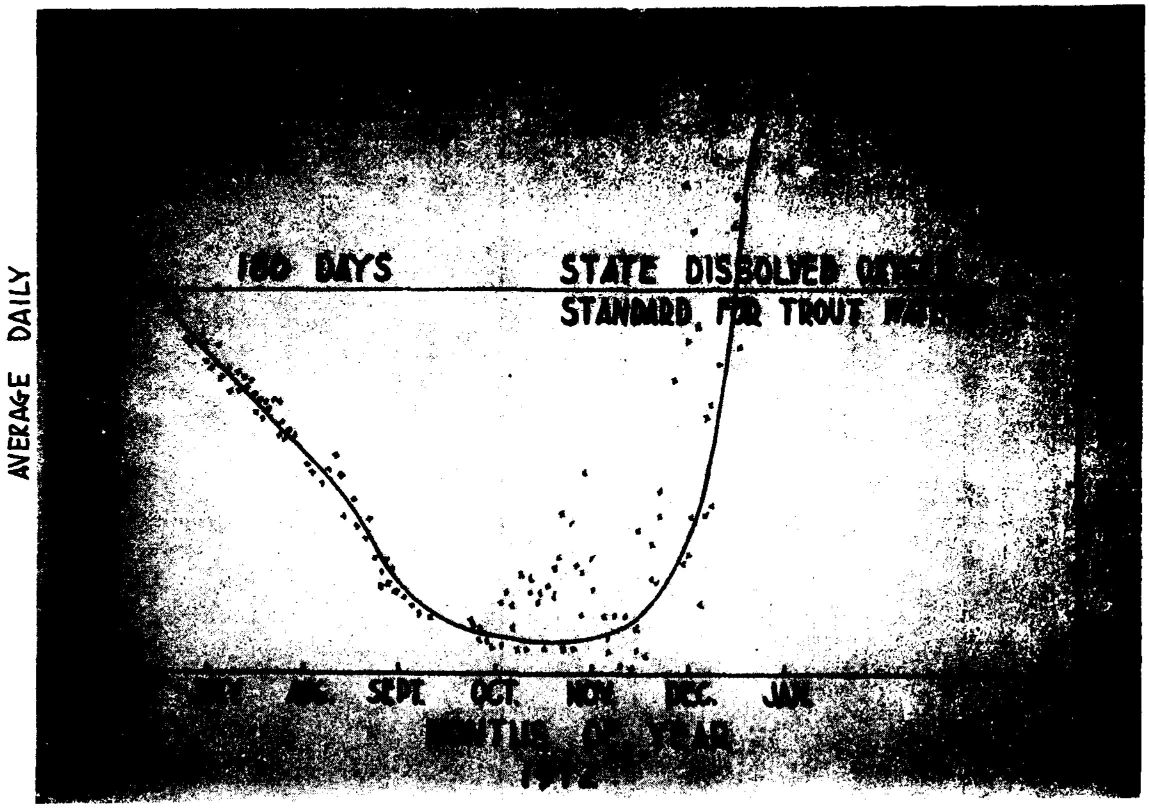
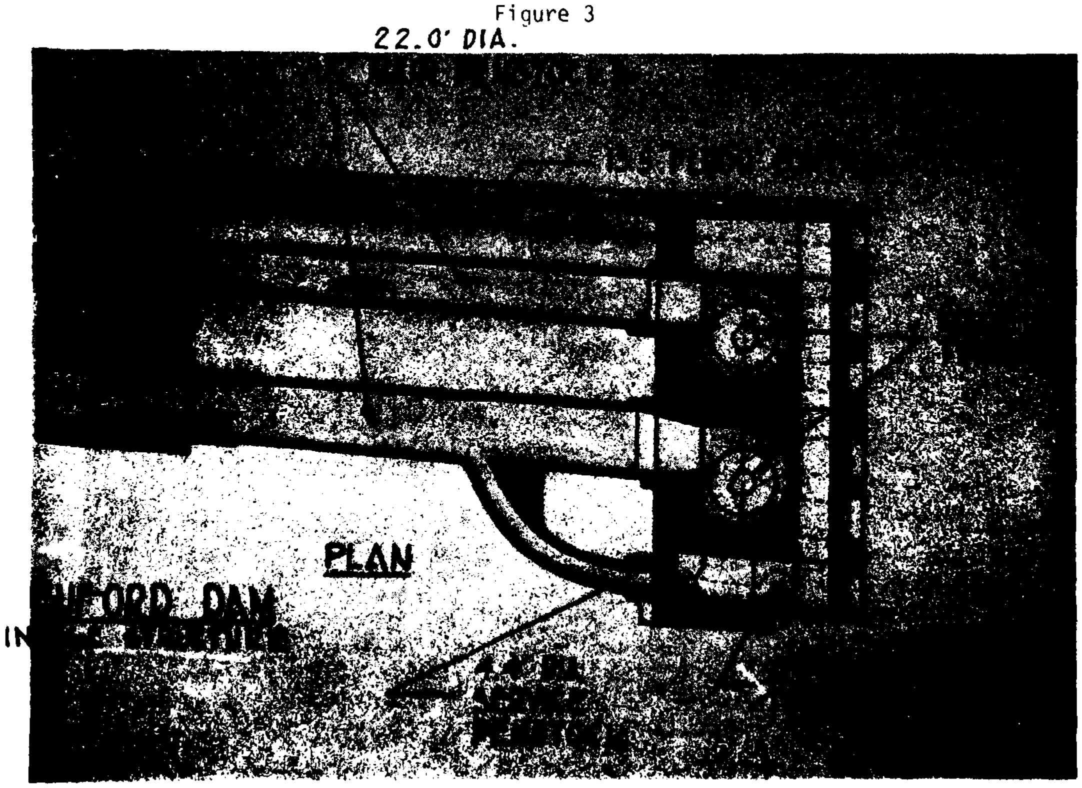



Figure 1

As indicated by Table 2, Buford Dam would appear to be representative of the more severe water quality conditions in the releases. Thus, this project will be discussed in greater detail. Figure 2 is a photograph of Buford Dam which was impounded in 1957, long before the establishment of water quality standards. The outlet works for Buford Dam are shown in Figures 3 and 4. It should be noted that the invert of the intake structure is on the bottom of the reservoir. Figures 5 and 6 show the morphology in the forebay and how a "trench" was actually excavated from the old riverbed to the powerhouse. The location of the outlet works combined with the unusual morphology create a very interesting impact on the water quality of the releases from Buford Dam. As previously mentioned, Buford is generally operated as a peaking power operation, i.e., a minimum release of about 550 cfs for about 18 hours per day and 8000 cfs for 6 hours. Figure 7 shows a dramatic correlation between increases in dissolved oxygen and flow. Figure 8 shows a similar increase in temperature with flow. It is speculated that these dramatic changes in dissolved oxygen and temperature result from changes in the withdrawal zone during peak discharges.

Figure 2

Figure 3



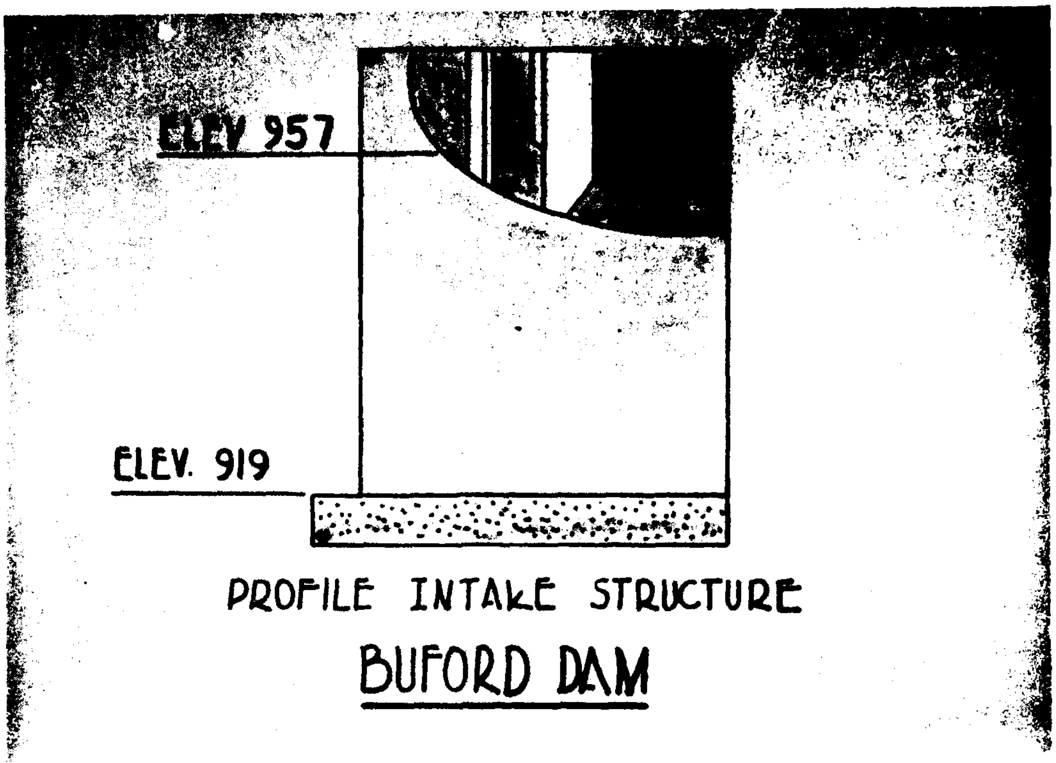
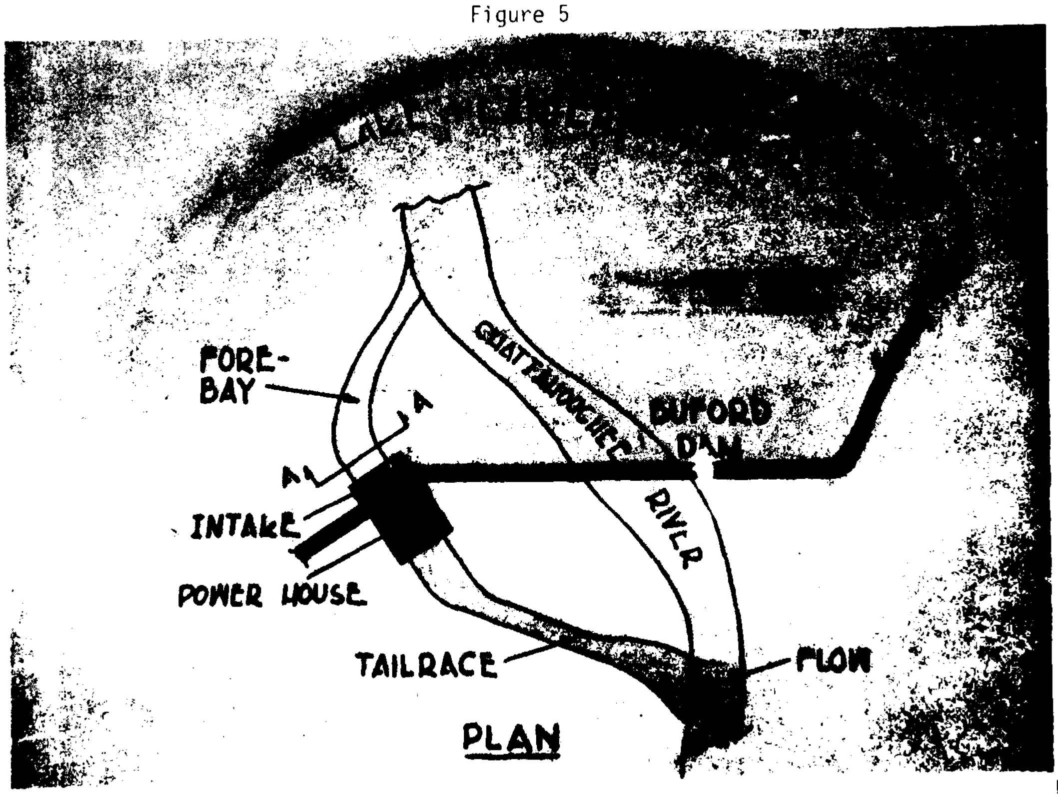



Figure 4

Figure 5



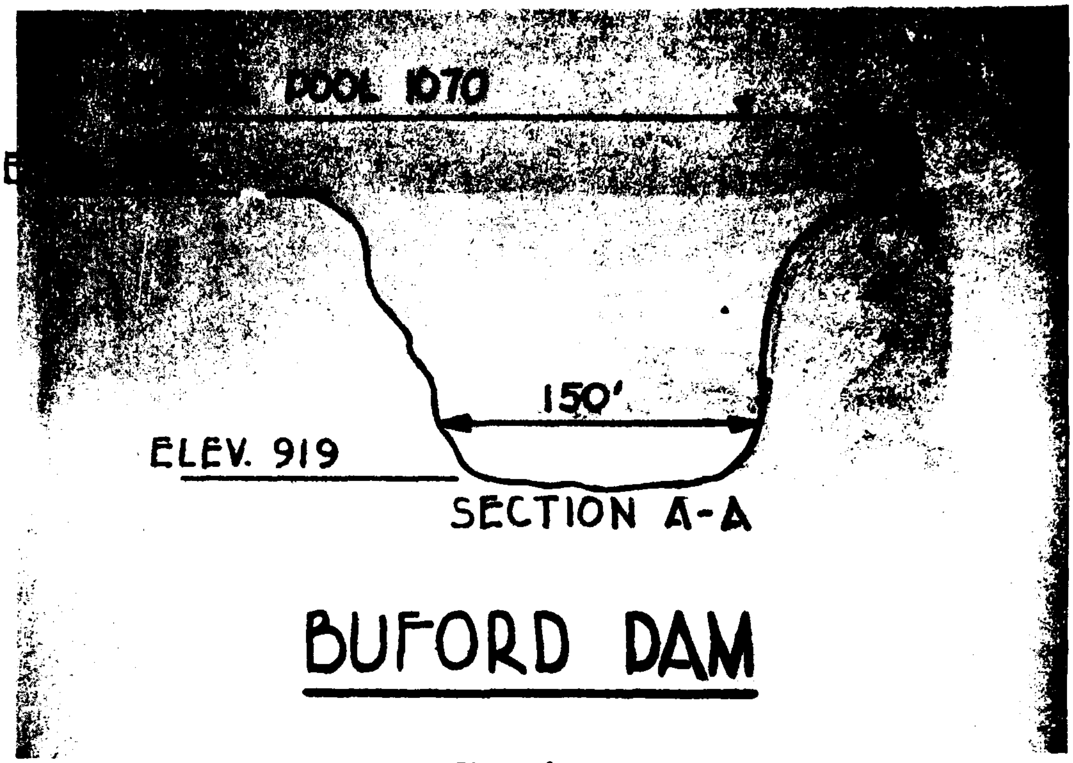



Figure 6

Figure 7

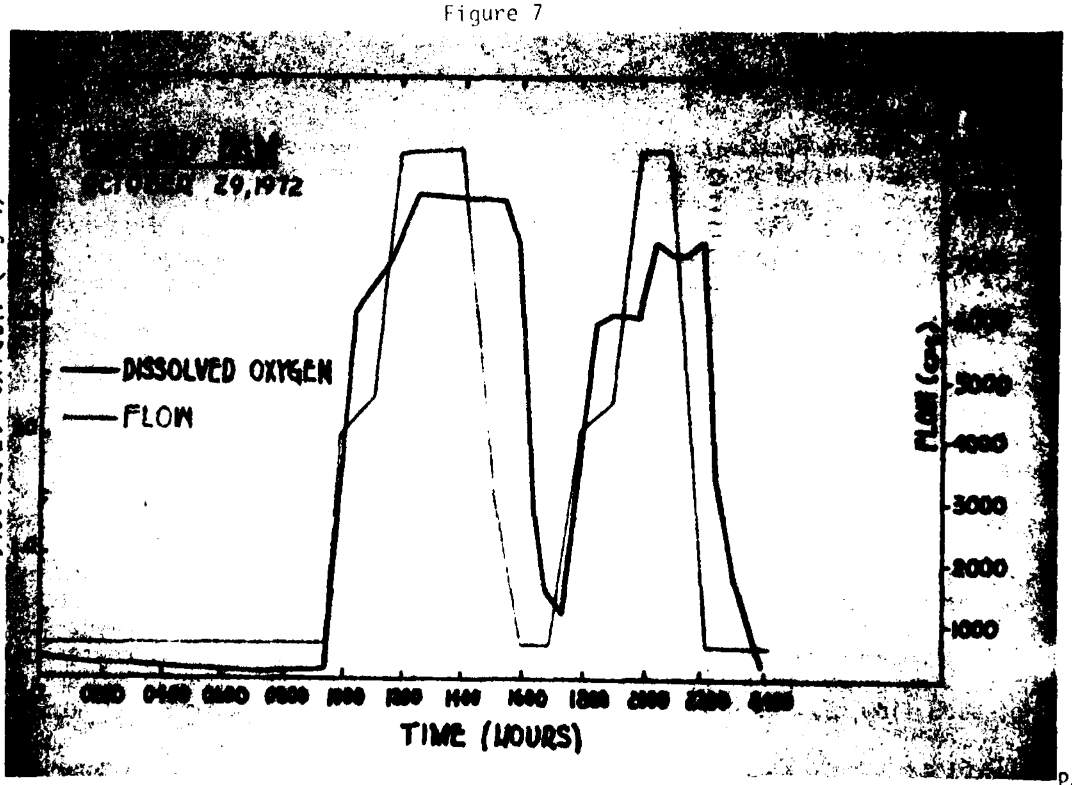



Figure 8

Based on the above observation that the dissolved oxygen concentration at high flow is considerably higher than at low flow, it would appear that the number of miles of river to reaerate to water quality standards would be less at high flow. However, as indicated in Table 2, the contrary is true. Even though the initial dissolved oxygen is higher at high flow, the increase in average velocity from about 0.75 miles/hour at low flow to 1.8 miles/hour at high flow, the greater depths, and submergence of shoal areas, approximately 9.5 miles of river is required to reaerate to water quality standards at high flow in contrast to 5.5 miles at low flow during the most severe condition. It would appear that the low dissolved oxygen levels and rapid and dramatic fluctuation in temperature and dissolved oxygen would have resulted in fish kills of trout in the tailwaters of Buford Dam. However, only very small and limited fish kills have been observed in the Chattahoochee River below Buford Dam. Trout were initially stocked in the Buford tailwater area in December 1957 and a progressive stocking program has developed. Low benthic macro-invertebrate populations have been reported in the tailrace area.

Fish kills have been observed at commercial trout fishing ponds which withdraws water from the Chattahoochee River about 2.5 miles below Buford Dam. These fish kills were generally noted in the Fall during periods of low flow and dissolved oxygen in the river. This problem with fish kills was resolved by a simple operational change at the trout fishing ponds which involved withdrawing water from the river only during periods of high flow.

In the winter of 1976, the State of Georgia Game and Fish Division commenced operation of their new Buford trout hatchery which withdraws water from the Chattahoochee River about 1.3 miles below Buford Dam. In the Fall of 1976, a massive fish kill occurred in the hatchery. When the Buford State hatchery was built, aeration equipment was provided in anticipation of the low dissolved oxygen levels in the releases. Thus, low dissolved oxygen levels, per se, did not appear to be a cause of the fish kill. Examination of the fish in the hatchery did not reveal any disease, parasites, or other problems associated with hatchery management. The Georgia Environmental Protection Division has reported the cause of the fish kill in the hatchery to be a result of the water quality of the releases from Buford Dam. It has been hypothesized that reduced toxic constituents producted in the anoxic hypolimnion of Lake Lanier (Buford Dam) remained as residuals after short term reaeration to cause the fish kill in the hatchery. Specific causative agents of the fish kill have not been defined. The Georgia Game and Fish Division introduced a strong oxidizing agent as treatment into the water withdrawn from the river and used in the hatchery during the Fall of 1977. This approach appeared moderately successful. A Joint Technical Task Force has been formed between the Georgia Department of Natural Resources, the U.S. Environmental Protection Agency and the Corps of Engineers to address the above condition and develop recommendations. Cooperative studies by this Task Force during the Summer and Fall of 1977 and 78 included data collection in the hatchery, river and lake. The data collection in the lake was primarily related to water quality characteristics. The study in the river below Buford Dam examined water quality, benthic macro-invertebrates, effects of water quality on fish movements, and collection of trout for pathological analysis.

Several preliminary conclusions can be derived from the various studies. The increases in mortality rates at the hatchery correlated with increases in total iron and manganese and a decrease in oxidation-reduction potential in the reservoir hypolimnion. This indicated the relationship of fish mortality within the hatchery system to the general water quality conditions during the latter period of summer stagnation. A greater incidence of gill lesions on trout in the tailwater also appeared to be related to increases in iron and manganese levels. The levels of these two elements is indicative of the reducing environment within the hypolimnion.

The fish sampling yielded no evidence that fish movement occurred in the river below the dam during the fall. In addition, there was no significant evidence of river fish mortaility caused by the hypolimnetic releases. Lesions were observed on the three species of trout and yellow perch, mainly on the gill. These lesions could be caused by a toxin but also could be due to stress from exposure to low levels of dissolved oxygen. However, these lesions were still found on fish collected from the downstream station, where dissolved oxygen levels are higher. SEM/EDX analysis also indicated exposure to environmental stress in fish from this section of river. In addition, the results of the histological examinations and the SEM/EDX analysis indicated that rainbow trout were affected the most, followed by brown and then brook trout. This corresponds to the mortality rates in the hatchery, rainbow suffering the heaviest mortality, with brown and brook sustaining lower losses.

It appears from the data collected during this study that direct effects on the riverine fish population are considerably more subtle than those operating on fish held under culture densities at Buford Trout Hatchery. However, the data do indicate that the riverine fish population is adversely affected physiologically, from toxins released from the hypolimnion and/or from low dissolved oxygen concentrations.

The U.S. Environmental Protection Agency has conducted a study on the trout mortality below Buford Dam and suggested that copper may be the toxic constituent. A bioassay study is planned for the fall of 1980 in a effort to define through a controlled experiment the toxic constituent responsible for the trout mortality. The experimental design is based on incrementally removing potential toxic constituents by various water treatment schemes as noted in Figure 9. The impact of oxygenation on the toxic constituent will also be investigated.

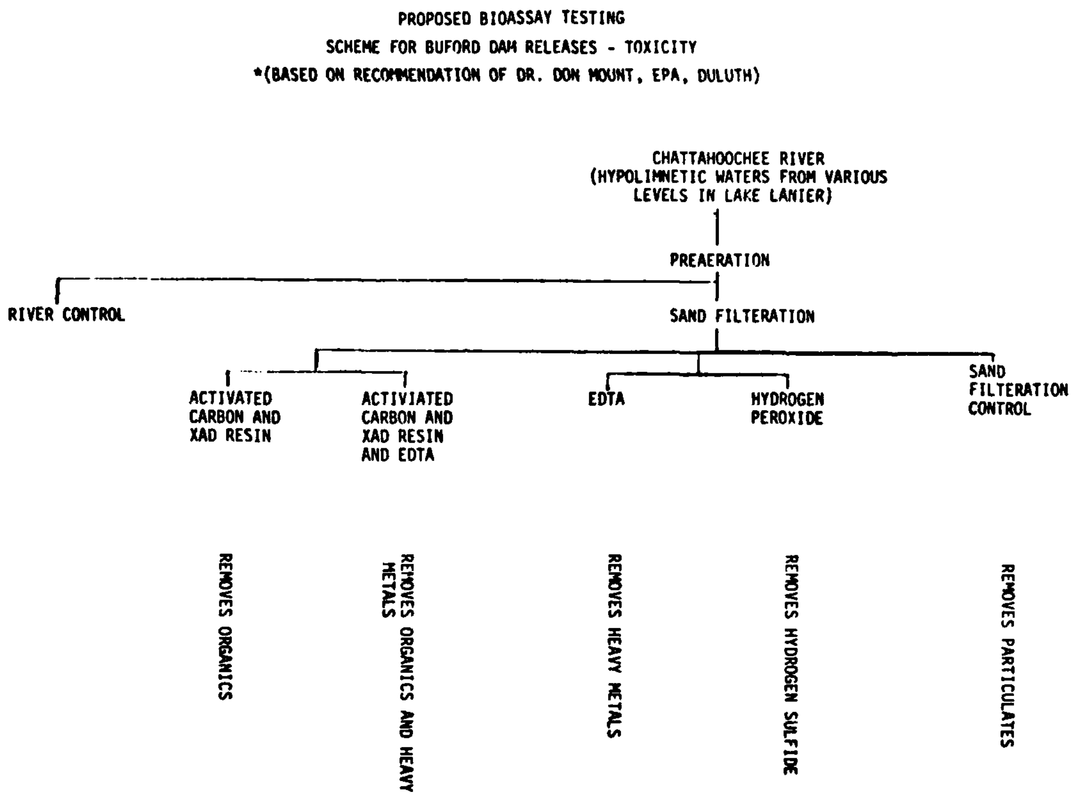



Figure 9

The water quality of the releases from Allatoona Dam can be contrasted to those of Buford with interest. As noted by Figure 10, the general slope of the curves is the same but the duration of intensity is considerably different from Buford. Furthermore, the relationship of flow to water quality is opposite to that at Buford as illustrated by Figure 11.

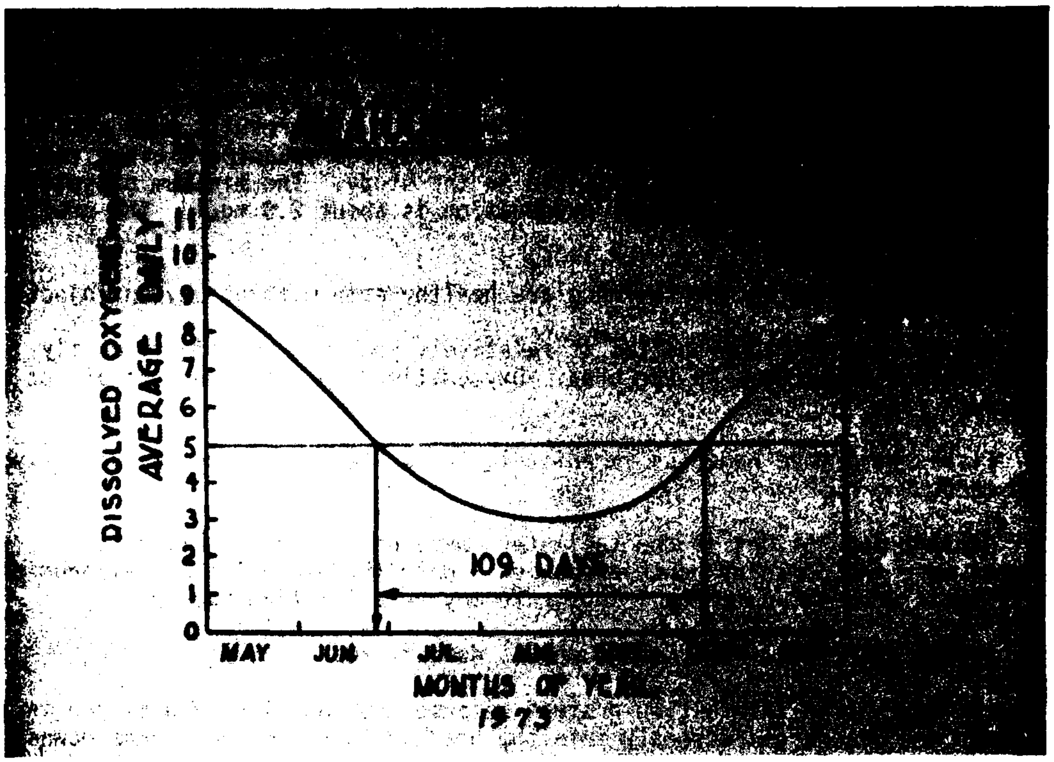
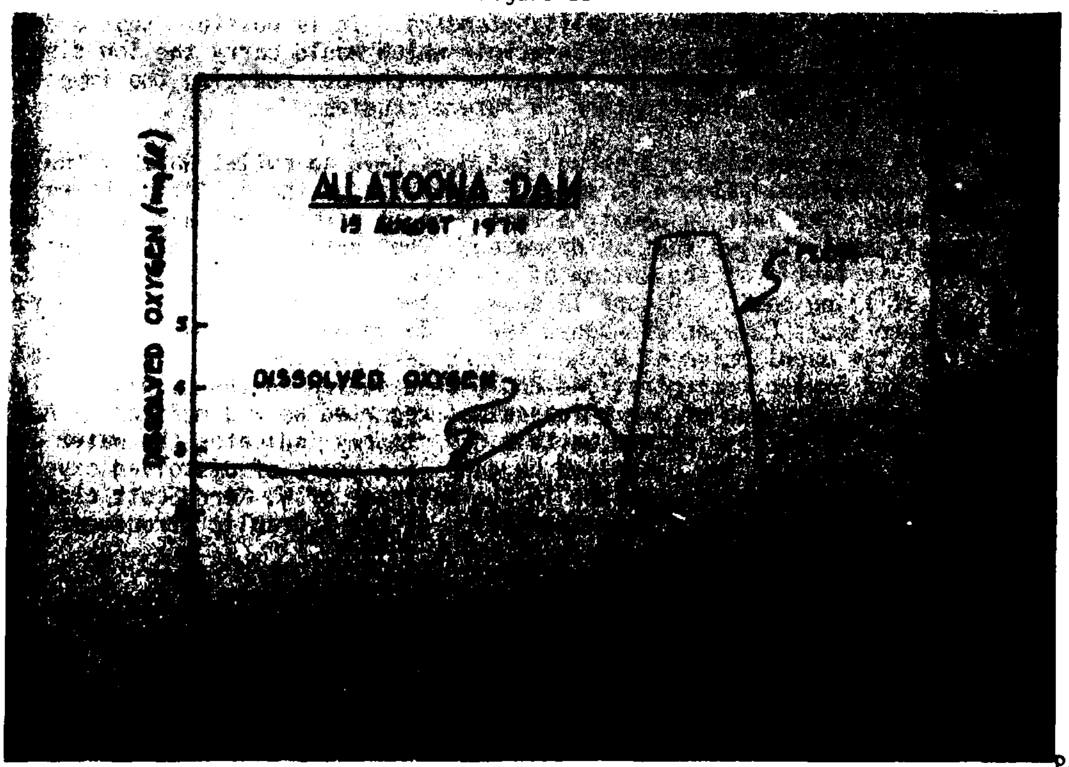



Figure 10

Figure 11



In conjunction with hypolimnion oxygenation testing at Clark Hill Reservoir in 1977 and 78, studies were conducted in the tailwaters on water chemistry, fishes, and benthos. The study was performed by the University of Georgia under contract with the Savannah District. The results from the year of oxygenation testing were compared to a year when oxygenation was not conducted. The results were also compared to normal healthy streams in the vicinity. Five stations spanning a river reach of about ten miles below the dam were utilized in the study. The minimum dissolved oxygen level in the tailwater without oxygenation is about 2.0 mg/l. The preliminary conclusions of this study were:

a. Fish population in the tailrace are healthy even without oxygen injections.

b. Growth rate of major species is relatively poor but not significantly different from other streams in the area. Oxygenation did not appear to affect the fishes growth rate.

c. Fishes were more numerous immediately below the dam during the year oxygenation was conducted.

d. Benthic populations in the tailwaters were poor with low diversity. Oligochaets were the dominant benthic species. With the exception of Chironomids, aquatic insects were not numerous. Substrate may be a limiting factor.

e. Snails and clams were more numerous downstream.

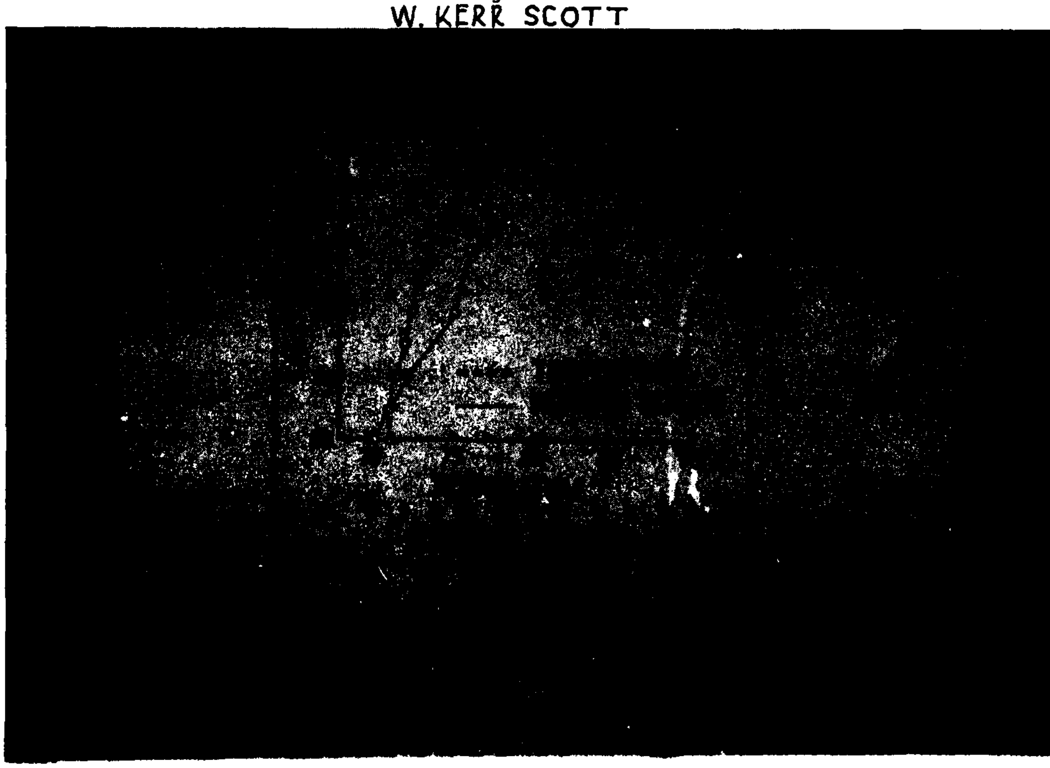
John H. Kerr is an interesting project because the low dissolved oxygen in the releases are discharged directly into the headwaters of another large downstream reservoir, Gaston Reservoir. According to a recent study, the low dissolved oxygen levels in the releases from John H. Kerr significantly affect the quality of the waters in the upstream portion of Gaston Reservoir. About 15 miles, or about half of the Gaston Reservoir length, would be required before the dissolved oxygen levels would reach 50 mg/l, the state water quality standard. It is possible that a density underflow current passes through Gaston Reservoir which would carry the low dissolved conditions into the already deoxygenated hypolimnion thereby reducing the impact. This item will need further investigation in future studies.

W. Kerr Scott does not have hydropower but does have an outlet which withdraws from an anoxic hypolimnion. Figure 12 shows a schematic of the outlet works relative to the dam and lake. The lake is about 55 feet deep at normal pool and has an outlet conduit of approximately twelve feet in diameter. The centerline of the outlet works is approximately six feet from the bottom of the lake. A strong hydraulic jump can be observed in the stilling basin. Figure 13 shows a temperature and dissolved oxygen profile for W. Kerr Scott Lake on 27 August 1975. Based on these low dissolved conditions within the hypolimnion of W. Kerr Scott Lake and the low level outlet works, low dissolved oxygen concentrations could be expected in the releases. The dissolved oxygen concentration of the releases was reported as 7.9 mg/l on 27 August 75. The 71°F temperature of release waters on this day clearly indicates the water is being withdrawn from the region of low dissolved oxygen. Six years of dissolved oxygen data from the electronic water quality monitor in the tailrace of W. Kerr Scott clearly confirm the exceptional reaeration characteristics of the hydraulic structure.


Figure 12

Figure 13

W. KERR SCOTT



A possible problem with low dissolved oxygen in the releases from Okatibbee Lake which has a low level release structure without a hydropower plant is currently under investigation. Indications are that downstream obstructions may be causing backwater conditions in the stilling basin and outlet conduit at Okatibbee Lake retarding adequate reaeration.

## CONCLUSIONS

Environmental concerns have been expressed for the downstream effects of releases from Corps' reservoirs in the Southeast. Hydrologic flow regime changes downstream of reservoirs can impact fishery habitat, wastewater discharge requirements, migration of anadromous fish, river swamps, wetlands, and scouring actions of the silts and increased turbidity.

Water quality conditions of the releases from reservoirs is becoming a greater item of concern. Anoxic conditions in the hypolimnion of the Corps' deep reservoirs in the Southeast combined with low level outlet works for hydropower operations produce a major water quality area of concern. Based on preliminary data, the releases from seven Corps reservoirs in the Southeast periodically release water of reduced quality. The primary parameter of concern has been dissolved oxygen. All of these reservoirs primarily release water through their hydropower plants. The hydraulic head is used to create electricity and is not available for reaeration. This demonstrates a direct conflict between energy and environmental concerns. Limited water quality control capability is provided at two of the seven projects mentioned above. The duration of low dissolved oxygen levels in the releases is generally about 4-6 months per year. The reach of river required for reaeration to water quality standards is variable but ranges from about 2 to 20 miles. In cases where minimum low flows are provided, generally the water quality of the releases is better at low flow than high flow. The dissolved oxygen concentration and temperature of the releases from Buford Dam during peaking hydropower operations are higher than during low flows. Furthermore, the reach of river required to reaerate to water quality standards during high flow at Buford Dam is significantly longer than during low flow. No significant fish kills have been observed in the river below Buford Dam. It has been hypothesized that reduced toxic constituents produced in the anoxic hypolimnion of Lake Lanier (Buford Dam) remained as residuals after short term aeration to cause the fish kill in the hatchery. Cooperative studies between the Georgia DNR and the Corps have been initiated to investigate the conditions produced by the releases from Buford Dam as related to the fish kill in the hatchery. It is envisioned that the intensive study of the effects of the releases from Buford Dam will provide better insight into the general condition associated with the environmental effects of reservoir releases.

The hydraulic structure at W. Kerr Scott Lake demonstrates an exceptional ability for reaeration of the release waters.

# SCREENING OF CORPS PROJECTS FOR NITROGEN SUPERSATURATION POTENTIAL

by

Glenn Drummond[1]

## Introduction

Supersaturation of atmospheric gases during spring runoff has been an aggravation to water managers in the North Pacific Division (NPD) for years. Fishery managers, water managers, and design engineers have been struggling together to minimize the impact of supersaturated atmospheric gases on the downstream migration of Salmon and Steelhead Trout fry and also to find means to reduce the solution of these gases into the river. The problem is well defined and progress is being made to resolve it.

An unexpected event occurred during the spring of 1978 in the tailwaters of the Harry S. Truman project on the Osage River, Missouri. Flow passing through low bays, left in the spillway section during construction, resulted in extremely high levels of dissolved nitrogen gas. The consequence was a massive fish kill that proved to be an embarrassment to the Corps. Subsequently, the Chief of Engineers directed his staff to identify potential problem sites to insure that the Corps would not be caught by surprise again. This directive was passed on to the field offices in the form of Engineer Technical Letter (ETL) No. 1110-2-239 dated 15 September 1978, subject: Nitrogen Supersaturation.

## Problems

Inclosed with the ETL were two computation methods recommended for use in the screening process. One method was excerpted from a report prepared for the North Pacific Division by Water Resources Engineers, Inc. (WRE). That report described an effort by WRE to develop a mathematical model of dissolved nitrogen gas concentrations in the lower Columbia and Snake Rivers. The second method was taken from a Bureau of Reclamation report of an effort to develop a generalized technique to model the influence of different types of hydraulic structures on dissolved gas concentrations. Equations were well described, but the limitations and sensivity of the variables and coefficients were not included. After initial computations were made, hydraulic engineers began to be concerned with the recommended values of coefficients. Too many cases were found in which results would vary from below to above critical concentrations in response to values of variables. Furthermore, Omaha District and Missouri River Division Engineers were not able to reproduce observed data with the recommended coefficient values. Concurrently, Jackson Brown, Nashville District, was requested by ORD to select a District project and perform a sensitivity analysis of the methods. The results of his analysis verified what was being reported by others, i.e., the methods would yield a wide range of results.

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## ORD Workshops

In response to the confusion and discontent that was being experienced by hydraulic engineers responsible for conducting the screening survey, a Corps-wide workshop was organized and hosted by ORD on 25 and 26 January 1979. The objective of the workshop was to have the people involved in the development of the two methods discuss formulation, constraints, sensitivity, and accuracy. Messrs. Hugh Smith and David Legg represented NPD and Mr. Perry Johnson represented the Bureau of Reclamation. Mr. John Grace, WES, was asked to critique the two methods in terms of the screening application. The NPD representatives talked at length about application of method to NPD problems. However, they were unable to relate to the problem at hand which was application of the method to structures that are only vaguely similar to the Columbia and Snake projects. Johnson presented a very thorough dissection of the BuRec method from formulation to application. He was able to point out inherent weakness of the BuRec method to potential users. In summary, Grace emphasized the greatest weakness in either method is estimating the time that gas bubbles are subjected to high pressure (approximately two atmospheres or greater). Such intangible terms as "effective" basin length, "average" depth, bubble rise time, and basin retention time are time related parameters to which the methods are sensitive. Grace further pointed out the basic hydraulic differences in spillway design philosophy between the Corps and BuRec that influences the accuracy of Figure 2: "Evaluation of K" in the description of the BuRec method.

## Tennessee Valley Authority

Mr. John Shipp, Tennessee Valley Authority (TVA), was invited to discuss their screening process. He reported that the TVA had not used any type of computation screening but had made field measurements in the tailwaters of some projects. They have observed some high concentrations up to about 140 percent of saturation. It was explained that these were short duration events and no biological harm has been encountered. Mr. Svein Vigander (TVA) reviewed the gas transfer equations and pointed out the critical elements.

## Conclusions

Mr. Earl Eiker, Office of the Chief of Engineers (OCE) summarized the discussions of the first day. He pointed out that it is obvious that precise computations are out of the question. However, for the purposes of screening, it matters little if the computed concentrations are 150 percent or 130 percent of saturation. In either case, the computations clearly show that a problem will probably exist under the given flow conditions. One must be especially concerned, though, when the computations yield concentrations of 110 to 120 percent of saturation. Under these circumstances, the screener must accept the fact that a potential for troublesome supersaturation exists and that field measurements will be required. Eiker's conclusions were that the computation methods are adequate for the screening exercise if applied with judgment and that the screening requirement would be completed as directed.

# GAS SUPERSATURATION AT RESERVOIR PROJECTS

By

Howard O. Reese[1]

## INTRODUCTION

This paper addresses the potential of gas supersaturation problems at Corps reservoir projects. Activities for transferring available technology on this topic to Corps field offices, the need for improving state-of-the-art technology and plans for accomplishing this task, and the ongoing study of gas supersaturation potential at reservoir projects within the Missouri River Division are discussed.

The previous paper provides information on this topic, also. It reviews the initial effort of the Corps to screen all Corps projects and identify potential gas supersaturation problem sites. Corps field offices are required to make this evaluation of their projects in accordance with the guidelines outlined in ETL 1110-2-239, subject: Nitrogen Supersaturation, dated 15 September 1978. In January 1979, the Ohio River Division (ORD) hosted a workshop to discuss the many questions raised on the use of the procedures outlined in this ETL. The paper contains a summary of the discussion and conclusions reached at the workshop.

This paper reviews those activities of the Corps that have taken place subsequent to the ORD workshop. Information presented supplements the previous paper.

## STATEMENT OF PROBLEM

Gas supersaturation has been identified as a potential environmental problem associated with releases from Corps impoundment projects. Incidents of fish mortality have been attributed to this dissolved gas problem. Fish mortality has been experienced below Corps projects on the Snake and Columbia Rivers in the North Pacific Division (NPD) and downstream of the partially completed Harry S. Truman project on the Osage River in the Missouri River Division (MRD). The incidents occurred in the Snake and Columbia Rivers in the late 60's and early 70's and in the Osage River more recently in 1978 and 1979.

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[1] Hydraulic Engineer, Engineering Division, Missouri River Division

## BACKGROUND INFORMATION

Supersaturation of dissolved gases in water can occur naturally or artificially so long as a situation exists where air can be entrained with water as small bubbles and subsequently placed under pressure. The gases of entrained air; nitrogen, oxygen, argon, carbon dioxide, and other gases, become dissolved in the water under pressure thus increasing the concentration. Falling water entrains air and if a plunge pool is of sufficient depth, it can become supersaturated. Air is entrained and placed under pressure naturally at waterfalls and artificially at man-made hydraulic structures at dams.

Gas supersaturation conditions occur in streams below many Corps projects during the operation of their outlet works and/or spillways. The degree of supersaturation is primarily dependent on the type of hydraulic structure, the depth of water within the energy dissipating part of the structure (stilling basin) or at the outlet end of the structure (tailwater), and the magnitude of flow (unit discharge for spillways). In general, the operation of hydropower turbines does not cause a supersaturation problem. High levels of total gas saturation in excess of the Environmental Protection Agency's recommended limit of 110 percent usually are associated with the operation of spillways. At spillway structures, entrained air is forced into solution as the flow is subjected to significant changes in pressure as it plunges into and passes through the stilling basin.

Fish mortality caused by subjecting fish to prolonged periods of excessive total dissolved gas pressure is referred to as gas bubble disease. Fish inhabiting supersaturated waters extract through their gills the high levels of dissolved gases into their circulatory system. After a prolonged period of time, the circulatory system becomes incapable of equilibrating to this condition and some of the dissolved gases within the body change from the dissolved form into the gaseous state. Gas bubbles will then form first on the external surfaces and later within the blood and tissues of the body, eventually causing death. Under these conditions, the fish that move from deep water to shallow water depths of five to ten feet are more susceptible to mortality. In shallow water there is less pressure and in the summer greater temperature. Water near the surface tends to be warmer and thus holds less dissolved gas at a given saturation level.

Laboratory tests show that fish mortality from gas bubble disease is related to the level of total dissolved gas pressure and the time of exposure. For example, about one week of exposure was required for juvenile salmon to die at 125 percent saturation; whereas, only a few days of exposure was required at the higher saturation levels of 135 to 140 percent. Tolerance to supersaturation varies between fish species. The major fish kills experienced in the NPD and MRD resulted from gas saturation levels in the range of 120 to 140 percent.

## METHODS OF PREDICTING GAS SUPERSATURATION

Two state-of-the-art methods for predicting gas supersaturation in a stream below a hydraulic structure are those used by the North Pacific Division (NPD) and the Water and Power Resources Service (WPRS), formerly the Bureau of Reclamation. The methods are described in ETL 1110-2-239.

The predictive method used by NPD was developed by Water Resources Engineers, Inc. in the early 70's. Field measurements of gas saturation at Corps projects on the Columbia and Snake Rivers were collected at this time also. From the field data, the required coefficients for the equations of the method were selected for each project. Some of the coefficients were adjusted in later years to better conform with additional field data. The spillways at these projects are all gate-controlled ogee type structures and the stilling basins are of similar design. This method of predicting gas supersaturation can be used to evaluate the effects of spillway structures that are similar to those on the Columbia River.

The predictive method developed by WPRS in the mid 70's is more general than the NPD method and it is applicable to a wider variety of hydraulic structures. After a fish kill from gas bubble disease occurred at one of their projects in 1972, the WPRS instituted a monitoring program to measure gas saturation at many of their reservoir projects. The hydraulic structures at these projects vary widely in type and size. Only a few structures are similar to the ogee type spillways on the Columbia River. Thus, a more generalized predictive method was developed. This method of predicting gas supersaturation can be used to evaluate the effects of hydraulic structures other than the ogee type structures that are found on the Columbia River.

## WORK GROUP ACTIVITIES
## CORPS COMMITTEE ON WATER QUALITY

The Corps Committee on Water Quality organized a work group in March 1979 to address the concerns of gas supersaturation potential at Corps reservoir projects. Members include David Legg, North Pacific Division; Tom Jenkins, Cold Regions Research Engineering Laboratory (CRREL); John Grace and Dennis Smith, Waterways Experiment Station (WES); and Howard Reese, Missouri River Division. The chairman of the work group is Mr. Legg.

At their first meeting in March 1979, the work group concluded that the following tasks should be undertaken:

1. Review criteria presented in ETL 1110-2-239 and prepare additional guidance where needed.
2. Disseminate information on acquiring accurate field measurements of gas saturation.
3. Investigate improved techniques for prediction of gas supersaturation below hydraulic structures.
4. Assist in the acquisition of a data base for use in developing improved techniques.

The work group assisted in preparing the DAEN-CWE-HY letter, dated 9 July 1979, subject: Nitrogen Supersaturation. This letter provided additional information on Corps-wide efforts in the area of nitrogen supersaturation at Corps reservoir projects. The letter also requested Corps field offices to furnish available field data on dissolved gas measurements to the Waterways Experiment Station, Attn: John Grace, WESHS.

In June 1979, the work group visited the National Marine Fisheries Service Laboratory which is located in a barge on the Columbia River near Prescott, Oregon. The purpose of the visit was to test and compare the gas tensionometer with both a gas chromatograph and a Van Slyke gas analyzer. The gas tensionometer is a relatively new device for measuring dissolved gas concentrations in the field. The test showed the measurements were accurate and more rapid than the two laboratory devices. Subsequently, arrangements were made under the Environmental and Water Quality Operational Studies (EWQOS) Program for this laboratory to make an independent check and evaluation of the tensionometer over a wide range of temperatures and pressures.

The work group has prepared several drafts of a proposed ETL entitled, "Measurement of Dissolved Gases to Determine the Degree of Nitrogen Supersaturation." It is anticipated that this ETL will be issued to Corps field offices as soon as possible. The draft report contains information on the types of in situ and laboratory methods that are available for measuring dissolved gases in rivers and lakes. Information is also presented on field techniques for site selection, collection of water samples, and preservation of samples. The information is summarized in the following two paragraphs.

Measurements in the Field - Two devices currently available for measurement of dissolved gas concentrations in the field are the gas saturometer and the gas tensionometer. The devices are relatively inexpensive and field portable. They measure the total dissolved gas pressure directly. The tensionometer is capable of measuring total gas pressure at depth whereas the saturometer can only be used for measurements near the surface. The principle of operation of these instruments is the same but they differ in the nature of their pressure sensing device. If temperature or dissolved oxygen measurements indicate that the stream is vertically mixed, the saturometer is the recommended device for field measurement. However, if the temperature and dissolved oxygen measurements change with depth, the tensionometer can be used, but with caution because it has not been fully tested. The devices should be calibrated before field measurements are taken.

Laboratory Methods - Several procedures are currently available for laboratory analysis of dissolved gas concentrations. These include gas chromatographs, mass spectrometers, and the Van Slyke Method. Gas chromatographic analysis is more accurate, the least expensive of the laboratory procedures, and is generally more readily available. Although a portable gas chromatograph has been used by personnel of CRREL and the Hydraulics Laboratory, WES, it should not be considered for use by a field office at this time. It is recommended that laboratory analysis conducted by gas chromatography be equipped with a Swinnerton stripping

chamber. In most cases, it will be necessary to have these analyses performed by a commercial laboratory. Determine beforehand that the selected laboratory is capable of performing the analysis and that the appropriate quality control procedures are enforced.

In 1980, the work group will investigate improved techniques for predicting dissolved gas concentrations below hydraulic structures. The Hydraulics Laboratory, WESHS, will analyze the dissolved gas data furnished by Corps field offices. They also are investigating the gas transfer characteristics of stilling basins. This laboratory is involved in reaeration research activities. It is anticipated that a report, possibly an ETL, will be prepared presenting information on the hydraulic characteristics of spillways and outlet works, the mechanics of dissolved gas supersaturation, and the equilibration processes.

## STUDY OF GAS SUPERSATURATION POTENTIAL AT MISSOURI RIVER DIVISION PROJECTS

The potential of gas supersaturation in streams below Corps lake projects within the boundaries of the Missouri River Basin was not considered to be a major problem prior to 1978. In 1978, the major fish kill in the Osage River below the Harry S. Truman Dam in Missouri created concern that the same problem might occur under certain operating conditions at other Corps lake projects. Subsequently, the current ongoing gas supersaturation study was initiated.

The major fish kill occurred in the Osage River below the Harry S. Truman Dam in late May and early June, 1978. The cause of this fish kill was attributed to the river being supersaturated with atmospheric gases, and it was determined that the fish died from gas bubble disease. The Missouri Department of Conservation estimated a fish mortality upwards of 420,000.

In 1978, inflows at the Harry S. Truman lake project were discharged through an uncompleted spillway. The spillway has four 40-foot bays. However, at the time of the fish kill the spillway crest was at elevation 600 feet, m.s.l. and the width of the slot in each bay was 36 feet. High inflows occurred the latter part of May and the discharge over the spillway exceeded 20,000 cfs for a period of 10 days. The depth of water in the stilling basin varied from 46 to 48 feet, as the tailwater elevation varied from 658 to 660 feet, m.s.l. The floor elevation of the stilling basin is 612 feet, m.s.l.

Upon receiving the initial reports of fish mortality due to supersaturated waters, arrangements were made for the NPD to loan a gas saturometer to Kansas City District. Initial measurements of total dissolved gas pressure were made in early June. The highest level of total gas saturation recorded was 133 percent. It is now estimated that the gas saturation levels were probably about 140 percent of saturation during the latter part of May.

In June 1978, arrangements were made with WES to conduct a model study of the spillway at the Harry S. Truman project for the purpose of evaluating this gas supersaturation problem. The results indicated that the placement of a deflector on the spillway would effectively reduce the high levels of supersaturation. The deflector would direct the flow more horizontally across the water surface rather than allowing it to plunge to the bottom of the stilling basin. It was concluded that an eight foot horizontal deflector at elevation 655 feet, m.s.l. should be constructed. The spillway deflector was subsequently completed in November 1978.

In view of the gas supersaturation problem on the Osage River below the Harry S. Truman Dam, a meeting was held in June 1978 with representatives from the Omaha and Kansas City Districts to discuss this topic. It was concluded a study would be made to determine whether or not similar gas supersaturation conditions might occur in streams downstream of other Corps lake projects. It was decided that both districts would begin measurements of gas saturation at each project as soon as possible to determine what effect, if any, the releases from spillways, outlet works, or powerhouses might have on downstream gas saturation levels. It was suggested that Omaha District acquire two Weiss gas saturometers for the purpose of calibrating and obtaining accurate measurements, and that Kansas City District could assist with the procurement of the devices and instruction in their use. This initial effort was the beginning of an overall gas supersaturation study in MRD.

During the summer of 1978, Omaha District made gas saturation measurements in the Missouri River downstream from the Gavins Point and Fort Randall lake projects. Below Gavins Point gas saturation levels of 110 to 115 percent below the spillway and 102 to 105 percent below the powerhouse were measured. Downstream from the Fort Randall spillway, the gas saturation levels were between 102 to 105 percent of saturation. In addition to the Harry S. Truman project, Kansas City District obtained measurements downstream of four other projects in Iowa and Missouri. The measurements below these projects were found to be in the range of 105 to 110 percent of saturation.

A preliminary evaluation of the potential for gas supersaturation problems at each lake project was made the latter part of 1978 in accordance with ETL 1110-2-239. The two methods described in the ETL for predicting nitrogen supersaturation below a hydraulic structure were used. An analysis was made comparing predicted values of dissolved gas concentration with values measured in the Osage River below the Harry S. Truman spillway and in the Missouri River below the Fort Randall and Gavins Point spillways. The results of this analysis indicated that the methods in the ETL did not adequately predict gas supersaturation for these types of structures.

In the absence of good predictive techniques, dissolved gas saturation levels are being monitored at each lake project whenever substantial releases are being made. In 1979, field measurements were made at 19 projects, 8 by the Kansas City District and 11 by the Omaha District. Measurements are generally taken in the lake near the dam and at several locations on the stream below the dam. Dissolved gas saturation levels

exceeded EPA's recommended limit of 110 percent on streams downstream from seven of these lake projects; Tuttle Creek, Milford, Perry, and Harry S. Truman in Kansas City District and Gavins Point, Fort Peck, and Chatfield in Omaha District. Per request in DAEN-CWE-HY letter, dated 9 July 1979, subject: Nitrogen Supersaturation, all field data collected on dissolved gas measurements are being furnished to the Waterways Experiment Station, Attn: John Grace, WESHS. This is an ongoing effort and measurements will continue to be taken in 1980. In addition to the saturometer, a tensionometer will also be used in 1980 by both Districts to measure total dissolved gas concentrations.

Despite the supersaturation conditions, no fish kills were observed on these streams in 1979 except for the fish kill on the Osage River. Other significant findings are that the equilibration of these streams was slow and the lateral mixing of streamflows was more gradual than expected.

High levels of gas supersaturation on the Osage River downstream from the Harry S. Truman Dam continued to be a problem during the first half of 1979. The problem continued despite the placement of the spillway deflector. A summary of the sequence of events in 1979 is presented in the following paragraphs. This information illustrates the relationship between magnitude of spillway discharge and degree of gas supersaturation and another relationship between effectiveness of spillway deflector and spillway crest elevation.

February, 1979 - The spillway crest had been constructed to elevation 666 feet, m.s.l. by late February when high flows from snowmelt occurred. The discharge over the spillway increased from 2,500 cfs on February 21 to 22,000 cfs on February 26 and the total dissolved gas saturation increased from 106 to 131 percent. A survey of the river for 30 miles below the dam showed dissolved gas levels were near 130 percent in the entire reach. The water temperature was about 2° Centigrade (C), and no fish mortality was noted.

Visual inspection of the spillway operating showed that the flow passed over the spillway deflector and plunged into the stilling basin. This confirmed the results of the model study which had shown that a spillway crest elevation of at least 676 feet, m.s.l. was needed for flows in the range of 20,000 to 30,000 cfs to strike the deflector. At lower spillway elevations, flows of such magnitude tended to override the deflector rendering it ineffective.

April, 1979 - Construction work resumed on the spillway after the flow had receded in March and by early April three bays were open to an elevation of 671 feet, m.s.l. The fourth bay was blocked off while concrete was poured to bring it up to the same level. At this time, high flows from spring rains again overrode the deflector. The discharge rose from 5,000 to 18,000 cfs in the two-day period of April 11-13 and this was accompanied by an increase in total dissolved gas saturation from 107 percent to 133 percent. The water had warmed to 12° C. The fish had become more active as natural spawning activity was stimulated by the warmer water. By April 16 another fish kill was underway. During the subsequent week, dissolved gas saturation levels peaked at

138 percent in the outlet area, persisted over 130 percent for about 30 miles below the dam, decreased to 125 percent 40 miles downstream, and decreased below 110 percent about 50 to 60 miles below the dam. Temperature measurements revealed isothermal conditions for about 20 miles below the dam. On April 24, the Missouri Department of Conservation conducted a fish kill census. They reported about 100,000 dead fish in the first 50 miles of the river below the dam.

June, 1979 - Flows subsided by the end of April and construction work resumed on the spillway. In late May a spillway crest of 681 feet, m.s.l. was attained. This was just in time to handle discharges up to 23,000 cfs in June. The spillway deflector proved quite effective in directing the flow horizontally across the surface of the stilling basin rather than allowing it to plunge to the bottom. Despite the high discharge, total dissolved gas saturation remained between 110 to 115 percent until the end of July. The saturation level then dropped below 110 percent and remained there while construction of the spillway was completed. On October 17 the spillway gates were closed and impoundment began.

## SUMMARY

Supersaturation of dissolved gases in a stream associated with releases from a reservoir project may cause an environmental problem. Fish mortality attributed to gas supersaturation has occurred in streams below Corps projects in NPD and MRD. The degree of gas supersaturation below a hydraulic structure is primarily dependent on the type of structure, depth of water in plunge pool, and magnitude of flow. Action has been taken to disseminate information and provide guidance on state-of-the-art technology to Corps field offices. A work group of the Corps Committee on Water Quality will be investigating improved techniques for prediction of gas supersaturation below hydraulic structures. It is anticipated that through research activities, the Corps laboratories, WHS and CRREL, will make further investigations of the gas transfer characteristics of stilling basins and the equilibration processes of streams. The MRD will monitor dissolved gas saturation levels at each lake project in 1980 whenever substantial releases are made. With this additional dissolved gas data, an attempt will be made to complete a final evaluation of the potential for gas supersaturation problems at each lake project.

# DISPOSAL OF DREDGED MATERIAL: OCEAN DUMPING CASE STUDY

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US ARMY CORPS OF ENGINEERS
NEW YORK DISTRICT

With the passage of the Marine Protection Reseach and Sanctuaries Act in 1972 and subsequent promulgation of the EPA Final Revision of Ocean Dumping Regulation and Criteria on 11 January 1977, Corps of Engineer Districts conducting ocean dumping or regulating such dumping under Section 103 permit authority, have been faced with implementing rigorous and largely state-of-the-art testing to evaluate the potential environmental impacts of the ocean disposal of dredged material.

In this talk I hope to present to you the experience of the New York District in implementing our Ocean Dumping Program and also to outline some of the problems we still face today. Before getting into that I shall give you a little backgound into the situation we face in New York with regard to dredging and the disposal of dredged material.

The New York District is responsible for maintaining some 240 miles of federal channels in the Port of New York (Figure 1)

These channels are used for a variety of purposes including recreational boating and mass transportation. But the major use of the harbor is a thoroughfare for waterborne commerce.

There are approximately 185 million (Figure 2) tons of commerce coming in and out of the port each year which represents about 12 percent of the nation's total waterborne commerce. The major commodity received is oil, followed by general cargo, such as containerized cargo, and bulk cargo (Figure 3). The largest container facility in the world is located at the Port Newark-Port Elizabeth complex in Newark Bay.

The navigation channels in the Harbor are for the most part not naturally deep. For example, Ambrose Channel which is the main entrance to the port, is maintained to a depth of 45 feet. This is over thirty feet deeper than its natural depth. This channel must be dredged each year to permit deep draft vessels to enter the harbor. In all the Corps removes an average of 7 million cubic yards of dredged material every year from the harbor. An additional 1-3 million cubic yards of material are dredged from slips, berthing areas, etc., by private industry, municipality, and semi-public agencies such as the Port Authority.

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Because of the scarity of land and the lack of other viable alternatives, about 95% of all the material dredged within the Port of New York is disposed in the ocean at the so called "Mud Dump".

This particular site has been used since 1914 and is located about 6 miles east of Sandy Hook, New Jersey (Figure 4).

The problem we face in this highly urbanized area is that the great bulk of the material dredged within the Port is fine-grained and contain a wide variety of pollutants, reflecting the overall poor water quality of the harbor.

The total wastewater discharges equal approximately 16% of the total fresh water flow into the Harbor. The wastewater often carries with it significant additions of various chemical contaminants such as heavy metals and also organohalogens such as PCB. These chemical constituents have a high affinity to become attached with suspended sediment particles. These contaminants can reside in the dredged material in a number of different ways; for instance, associated with the water in the dredged material or in association with the organic material. They can actually be part of the mineral itself either inside the crystalline lattice or bound around the face of the particle, as an organically bound fraction or a reducible coating (Figure 5).

The various numbers on the fractions in Figure 5 indicates the relative release of these materials to the water column. For instance, if the contaminants reside in the interstitial water, they can be released more readily than if they reside within the crystalline lattice. One of the major findings of the DMRP was that total sediment or bulk analyses of thse chemical constituents gives little indiction of potential water quality or biological impact.

Recognizing this fact, the Ocean Dumping Criteria promulgated by EPA on 11 January 1977 specify that biological testing be utilized to demonstrate environmental acceptability for ocean dumping. Figures 6 and 7 outlines the testing requirements as specified by the Criteria.

## Implementation Manual and District Guidance

I would like to emphasize that at the time of the publication of the Ocean Dumping Regulations and Criteria, testing of dredged material using bioassays essentially were state-of-the art procedures. An Implementation Procedural Manual (1977) was prepared by a Joint EPA/COE Technical Committee on Criteria that described the procedures to be used in conducting the required tests.

While this Manual has been a necessary and useful resource, it must be kept in mind that it was prepared for a national audience and thus by its nature could not answer all the problems on the local level.

For these reasons the New York District published Guidance for Performing Tests on Dredged material to be Disposed in Ocean Waters (US Army Engineers, NY District, 1978).

This guidance was prepared in conjunction with EPA -Region II and outlines specific regional requirements of our respective agencies and tries to ensure uniformity in the administration of the program. For example, this guidance discusses how to select sampling sites, which species to use in each of the tests, the required chemical constituents to be analyzed in bioaccumulation tests, detection limits for each chemical consituent and quality control requirements. It also summarizes each of the tests to be performed and indicates the types of data to be submitted to our office.

The New York District requires that applicants and laboratories furnish the raw data and daily observations records. All statistical analyses and interpretation as to conformity with criteria are made by our office.

Cost of Testing This testing can be quite expensive. One complete bioassay with bioaccumulation as discussed above generally costs in the neighborhood of $10,000 as performed by commercial laboratories in this area where competition is fairly intense. This figure includes just the cost of supplying the raw data, with no interpretation provided. Price quotes from professional Environmental consultants and laboratories run considerably higher. This $10,000 figure also represents the cost to run one bioassay with samples from several different locations composited together. If individual bioassays were to be run on each sampling site, costs obviously would increase according to the number of tests run. At present our office has reviewed a total of about 100 individual bioassays, including those submitted by applicants for Section 103 permits and also those performed for Federal dredging projects.

Evaluation of Test Results For the liquid and suspended phases, we have not encounterred any cases where the Criteria would be violated after consideration of initial mixing. Interpretation in these phases is fairly straightforward. Essentially, the Criteria are met if the concentration of dredged mterial in the water, after allowance for initial mixing does not exceed a toxicity threshold defined as 0.01 of a concentration shown to be acutely toxic to a test species in the bioassay. The acute toxic level is defined to be the LC 50, that is the concentration of dredged mterial which causes a 50% mortality. Our findings are consistent with those reported by the Dredged Material Research Program, recently completed, which concluded that water quality impacts associated with the open water disposal of dredged material are negligable in most cases.

In the solid phase test, the procedures utilized have been largely untested and state of the art, and interpretation of results in terms of the criteria has been more difficult.

The Evaluation of the tests first involve a statistical comparison of observed mortality in test animals exposed to the proposed dredged material vs. mortality in animals exposed to a reference sediment. A determination must then be made based on these results as to whether a disposal would "cause unreasonable acute or choronic toxicity or other sublethal adverse effects".

It is important to realize that statisticially significant effects in a bioassy do not necessarily imply that an ecologically important impact would occur in the field. Unfortunately, there are no quantitative methods for estimating the magnitude of such a difference that might reliably be assumed to predict adverse impacts in the field. As a guide, the Implementation Manual recommends that statistically significant mortality differences of at least 10% are necessary in most cases before prediction of probable impact can be made. The use of this 10% "threshold" minimum difference, however, is not universally accepted. In fact its use by our office in permit decisions is one of the issues in litigation as a result of a lawsuit filed by the National Wildlife Federation. In addition, the Fish & Wildlife Service routinely recommends permit denial if any statistically significant mortality occurs.

<u>Bioccumulation</u>
Since 15 February 1979, at the request of EPA - Region II, the NY District has been requiring laboratory bioaccumulation analyses of the solid phase test organisms. Prior to that date, we had required only the three phase bioassay and the use of limited field data to interpret bioaccumulation potential.

There were several reasons why we had taken this position:

1. <u>Preference of Field Studies</u>: Field studies were the method preferred by the Implementation Manual for assessing bioaccumulation potential because of the difficulty of simulating in the laboratory actual field conditions such as mixing and sediment transport. Some field studies had been done at that time by our office and there were additional studies being developed. Results to date have indicted no significant uptake by dumpsite organisms relative to uptake by organisms far removed from the influence of the dumpsite.

2. <u>Analytical capability of laboratories</u>. Our previous experience with the local commercial laboratories made us skeptical that accurate quality chemical data could be obtained. The need for interlab calibration and a quality control program was recognized as essential, if reliable data was to be obtained and a credible program established.

3. <u>Interpretation of bioaccumulation data</u>: As is pointed out in the Implementation Manual, "there are very little data for marine species upon which to base an evalution of the meaning of a specific contaminants in the species in question.

The Manual nevertheless recommends the environmentally protective approach of assuming that any statistically significant difference in tissue concentration between control and exposed organisms is a potential cause for concern. However, it points out that in making the final assessments a number of facts must be objectively considered such as:

1. The magnitude of bioaccumulation shown,

2. the toxicological sigificance,

3. portion of sampling sites showing bioaccumulation,

4. number of different constituents showing bioaccumulation,

5. the position in human & non human food webs of species showing uptake,

6. other factors relevent to disposal.

Since our control sediment was a clean sand while the dredged sediments were primarily fine-grained we anticipated that we would probably see statistical differences. What each difference might mean in terms of impacts on organisms and on the human food chain was not clear.

Present Status

At the present time 11 Permit applications with bioaccumulation data have been reviewed and are shown in Table 1. Some observations to be made as follows:

a. Statistically significant differences in uptake between test and control organisms of at least 1 constituent by a least 1 species have been observed in all but one case.

b. PCB's & petroleum hydrocarbone were the constituents of concern in most of these cases and were found in the polychaete worm in each case. PCB's also occurred in the shrimp, in 2 cases and in the clam in one case, while petroleum hydrocarbons were found in the shrimp in 2 cases and in the clam in 4 cases.

c. The statistically significant PCB valves ranged from 0.07 to 0.62 ppm; in all cases but one it was less than 0.5 ppm or less than an order of magnitude below FDA limits for human consumption.

d. The significant petroleum hydrocarbon values ranged from 0.43 to 23.0 ppm, which are within normal background levels as reported by Goldberg (1976).

e. No significant mortality in bioassays were observed for any of test species in these cases.

TABLE 1. LEVELS OF CONSTITENT (ppm) IN TEST ANIMALS EXPOSED TO DREDGED MATERIAL

| APPLICANT - WATERWAY | Petroleum Hydrocarbons | | | PCB (ppm) | | | Mercury | | | Cadimum | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | shrimp | worm | clam | shrimp | worm | clam | shrimp | worm | clam | shrimp | worm | clam |
| U.S. Gypsum Co. | .48 | 13.6* | 2.1 | ND | .29 | ND | 1.3 | 2.8 | 2.3 | ND | ND | ND |
| Refined Syrups & Sugars Corp. | 2.0* | 0.2 | 0.2 | 0.2* | 0.07 | 0.03 | 0.3 | 0.2 | 0.09 | 0.16 | 0.15 | 0.02 |
| Dept. of Navy | 0.61 | 22.9* | 5.5 | ND | 0.62* | ND | ND | ND | ND | 0.31 | 0.37 | 0.46 |
| Jackson Engineering Corp. | 0.18 | 15.0* | 3.7 | ND | 0.19 | ND | ND | ND | ND | ND | .28 | ND |
| Seatrain Realty Corp. | 0.1 | 1.7 | 13.0* | 0.04 | 0.34* | ND | ND | ND | ND | 0.30 | 0.33 | 0.46 |
| Monsanto Corp. | - | 7.0* | - | - | 0.17 | - | - | ND | ND | ND | ND | ND |
| Port Authority- Newark Bay | 0.2 | 15.0* | 3.7 | ND | 0.30* | ND | ND | ND | ND | ND | ND | ND |
| Port Authority- Hudson River | .6 | 4.2* | 4.2 | ND | 0.32 | ND | ND | ND | ND | ND | ND | ND |
| Westchester Co. | 1.25 | 1.0 | .61 | 0.04 | 0.06 | 0.05 | 0.24 | 0.24 | 0.22 | 0.48* | ND | ND |
| Paktank Atlantic Co. | 0.74* | 0.81* | 0.43* | 0.20* | 0.17* | 0.16* | 0.41 | 0.75 | 0.38 | 0.44 | ND | ND |
| NYC Dept of Water Resources - | 18.6 | 10.0 | 11.0 | ND | ND | ND | ND | ND | ND | .68 | ND | ND |

*-Indicates statistically significant differences from control animals
N.D. - Not detected

Shrimp - Polaemon etes pugio
Worm - Noreis virens
Clam - Mercenaria mercenaria

Recognizing the relatively low magnitude of bioaccumulation observed (with respect to FDA limits for PCB) and also with respect to the published literature for petroleum hydrocarbons (Goldberg, 1976), the fact that food chain biomagnification has not been demonstrated to occur in the marine environment, (Macek et al, 1979, Pearce, 1980) that studies carried at the dump site (O'Brien & Gere, 1979) do not indicate increased uptake of these constituents over background and also noting the absence of acute toxicity in the solid phase bioassay, this office concluded that for these cases, there would be reasonable assurance that no unreasonable acute or chronic toxicity or bioacculation of toxic materials into human food chains would occur. EPA has agreed with this interpretation for petroleum hydrocarbons. However, where statistically significant levels of PCB were found, they have determined it to be in non-compliance with the Criteria. The Fish and Wildlife Service and National Marine Fisheries Service have also recommended permit denial where statistically significant levels of PCB were found.

For 2 of the applications in question the District has submitted reports to OCE recommending that a "Waiver of the Criteria" be sought, as provided for in the Regulations, based on Ecnomic need and the Absence of feasible alternatives.

The actual waiver request must be made to the Administrator, EPA by the Secretary of the Army. To date no formal waiver request has been made.

At the Washington level, OCE has coordinated with the concerned agencies and an Interagency Task Force has been formed to evaluate the situation and is to submit recommendation by 28 February 1980.

Meanwhile, the NY District has been developing long range plans to develop other disposal alternatives (Suszkowski, 1979). An Environmental Report was prepared under contract with MITRE Corp (1979) that evaluated impacts associated with ocean disposal and also identified other potential alternatives. Disposal in subaquous borrow pits and capping "contaminated" materials with clean material as well disposal on the upland are being actively investigated as to their feasibility and effectiveness. However, at present, ocean diposal remains the only viable alternative in the short term for dealing with the bulk of the material dredged from New York Harbor.

In Summary:

1. State of the art test procedures have been and are continuing to be used in the regulatory program to evaluate dredged material proposed to be ocean disposed.

2. There are significant gaps in our ability to properly interpret and assess the signficance of such test data.

3. Dredging projects are being held up due to the inability to resolve interagency differences regarding the criteria and also due to the lack of disposal alternatives. This has been having serious implications and is threatening the economy and vitality of the Port of New York.

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US Army Corps of Engineers, 1979 Guidance for Performing Tests on Dredged Material to be Disposed of in Ocean Waters. US Army Engineer District, New York.

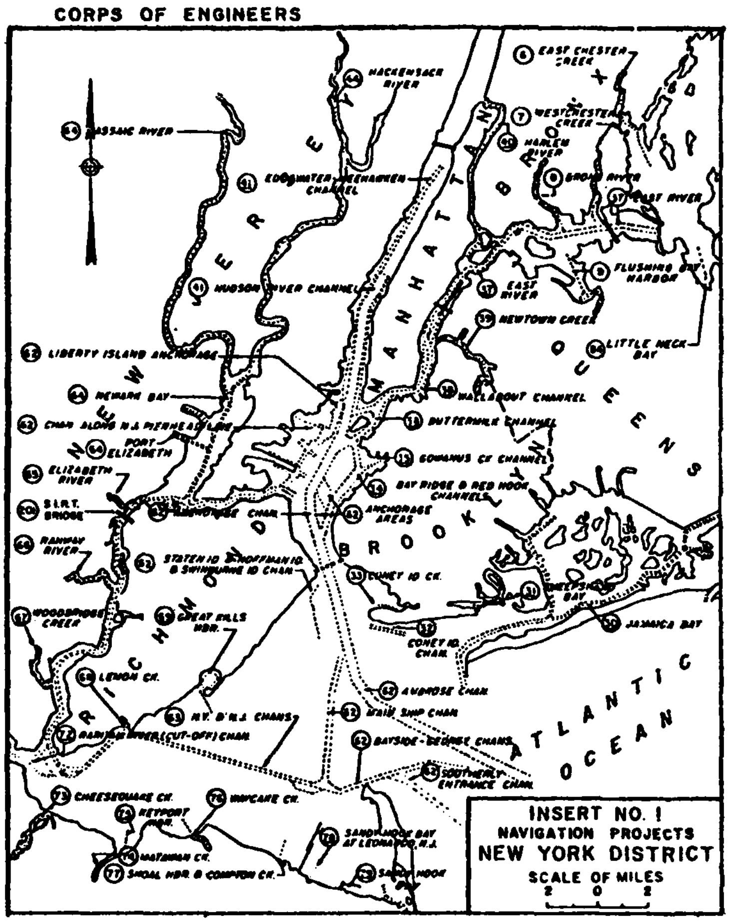
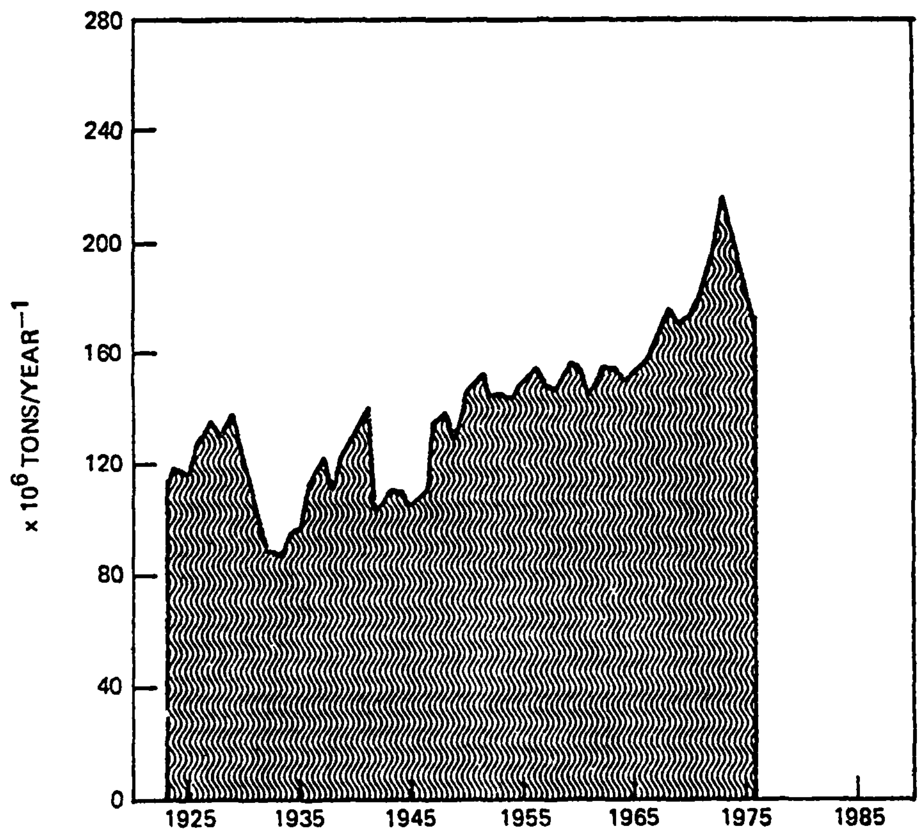
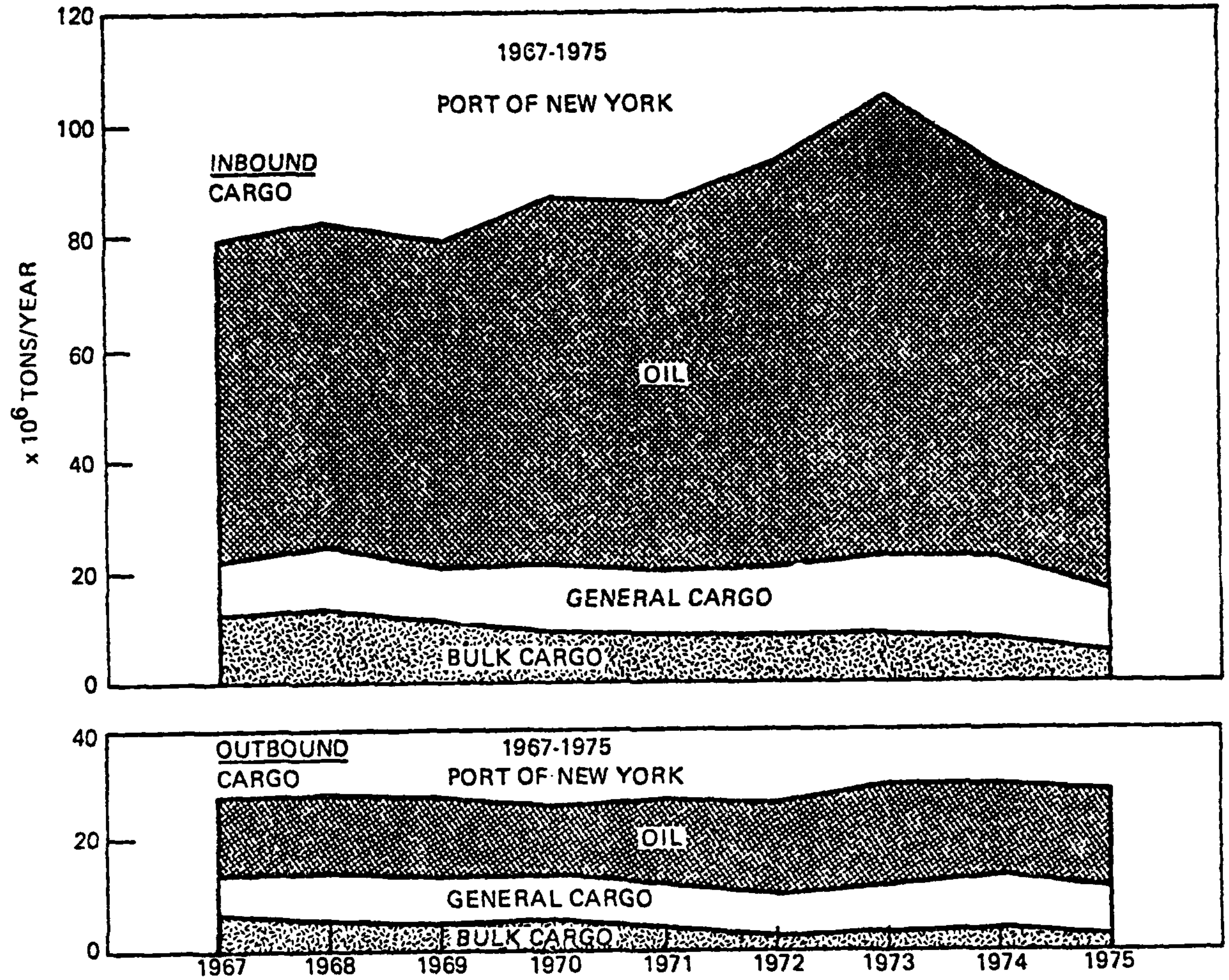



**FIGURE 1**
**NAVIGATION PROJECTS OF THE NEW YORK DISTRICT**



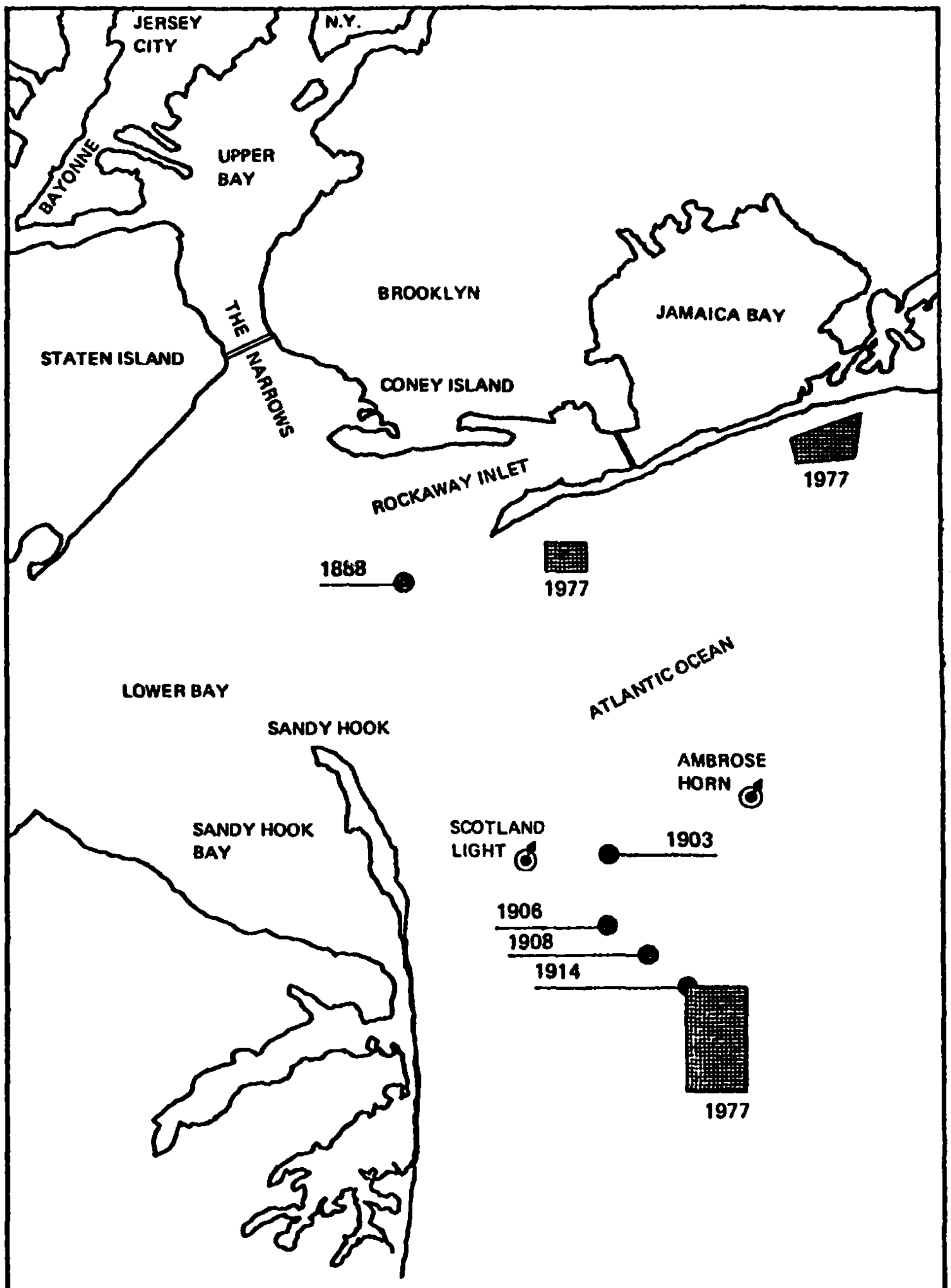

SOURCE: U.S. Army Corps of Engineers. 1977. Unpublished data.

FIGURE 2
TOTAL COMMERCE OF THE PORT OF NEW YORK 1924-1975



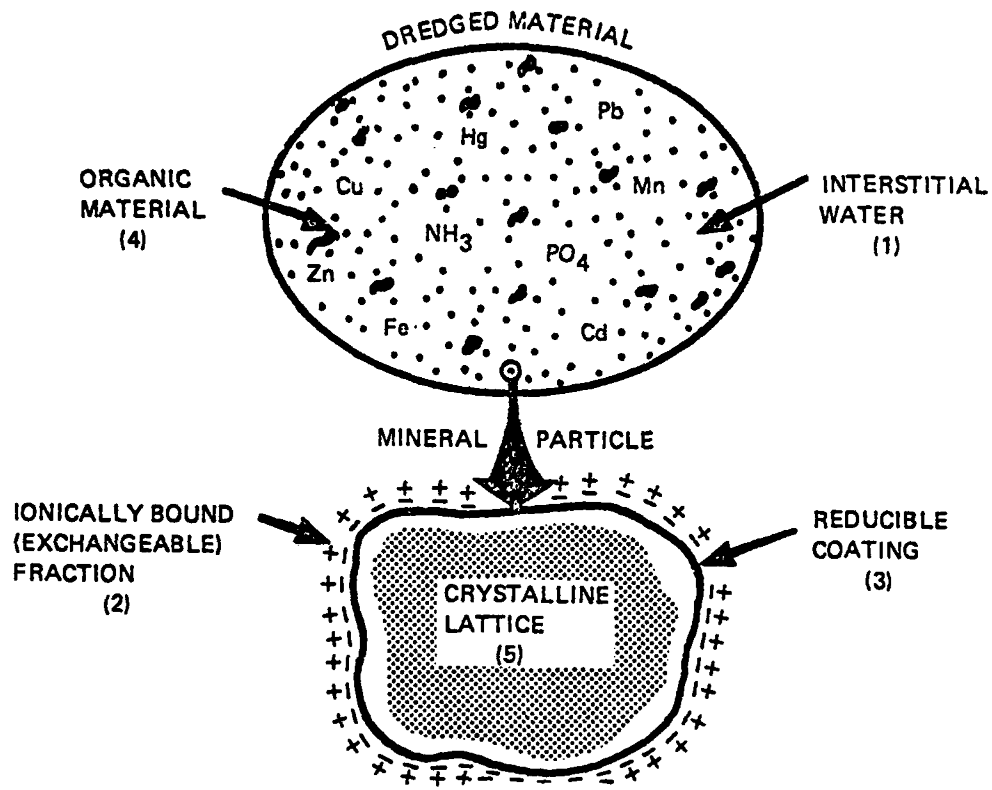

*SOURCE: U.S. Army Corps of Engineers, 1977. Unpublished data.*

FIGURE 3
COMMODITIES OF NEW YORK HARBOR COMMERCE 1967-1975




SOURCE: U.S. Army Corps of Engineers, 1977. Unpublished material.

FIGURE 4
AREAS INFLUENCED BY DREDGED MATERIAL DUMPING




*SOURCE; U.S. Army Corps of Engineers, 1977. Unpublished data.*

FIGURE 5
CHEMICAL CONTAMINANTS OF DREDGED MATERIAL

# WATER QUALITY EVALUATION - AN ESTUARINE CASE STUDY

BY

JOHN F. SUSTAR 1/

Environmental awareness of potential impacts from dredging operations in San Francisco Bay began in the late 1960's. Initially the San Francisco District funded the U.S. Fish and Wildlife Service in 1967-69 to study the effects of dredging and disposal operations in San Pablo Bay. Critque of the study raised many questions not only on the adequacy of the study but also on additional areas of uninvestigated potential impacts in an estuarine system. The early seventies were years of monthly confrontations between the various regulatory agencies over the permitting of both maintenance dredging and new construction dredging. Rigorous impact evaluation procedures were ignored in favor of easily interpreted numerical limits on bulk concentrations of constituents. Relationship of these levels to biological impact was totally unknown. With some of the constituents, natural deposits within the bay exceeded the permissible concentration. The San Francisco District responded with an interdisciplinery applied research program. The program was initiated in 1971 and completed in 1977 at a cost of $3 million. The study has resulted in a complete reorganization in the permitting of dredging operations. The District in conjunction with EPA Region IX and the State Regional Water Quality Control Board has implemented regional guidelines for evaluating dredging and disposal. The guidelines have reduced time, costs and confrontation for the majority of projects while providing assurance for protecting the environment. This paper will present some of the philosophy in the conduct of the study with some examples which resulted in its success.

First, the following premises guided the study:

a. Environmental concerns about dredging resulted in defensive research. The studies conducted addressed very specific environmental impact questions. The success of the study depended upon how well these questions were initially defined and how much the questions were refined as the studies progressed.

b. Generalized statements on the "waste" would lead to invalid conclusions. An impact is a change induced by a specific condition. The impacts at a disposal site which accepts several types of wastes may be associated with only one waste or with synergistic or antagonistic responses between wastes. Even within the "sediment waste" major differences between effects are seen with clays, silts and sands. In a positive sense, clays serve as a scavenger for liquid wastes or constituents thereof.

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c. Changes in chemical, biological and some physical baseline conditions in an estuarine system can not be used to interpret direct cause and effect relationships in the system. Daily, seasonal and other cyclic variations in the system are poorly defined and can result in major variations in interpretation. Also, the interactions between these variations are unknown.

d. The study of impacts must separate or isolate causes of those impacts to the greatest extent possible. One example is separating the effects of the actual dredging and disposal operation from the effects of the navigation facilities. Changes are continuously occurring with man's activities in the estuary and with natural processes.

e. Definition of the system is essential for transfer and correlation of information between work elements within the study and between studies in other marine systems and other environments. An example is the definition of turbidity. Turbidity must be defined in terms of the impact which is being evaluated. Algal production would be evaluated using a light transmission where an animal response analysis would use sediment concentration for stress analysis and visibility for predation patterns. In both cases sediment concentration and light transmission, the system also must be defined in terms of organics, type of sediment, salinity changes and hydrodynamic variations for both tidal and freshwater inflow conditions. All of these factors will influence the variation and the interpretation of data.

The study was set up in three tiers. The first tier was aimed at defining the physical, chemical, biological and mechanical systems associated with the dredging and disposal operations in San Francisco Bay. Of these studies elements, only the biological sampling was established as a baseline type study. The other three addressed mechanisms in the system along with the variations. The second tier study elements addressed the relationships between each of the four systems. The third tier elements addressed the relationships between all of the four systems which resulted in an interpretation of mechanisms of action in the estuary during the dredging and disposal, what parameters appeared to control the events and what could be expected during future operations.

Each study element was conducted to maintain flexibility, to modify and/or refine data collection and analysis, to address arrays of interactions using a matrix approach and to identify variations in data. All of these dictated that the study process involved a continuous apologia of study element objective, method and interpretation and the required interchange between study elements.

The following are examples which illustrate the above philosophy.

The first example is the definition of the sediment plume during disposal. The initial work involved the typical monitoring of the water column at three prescribed distances behind the dredge. The initial monitoring was unable to clearly delineate the release of sediments from the dredge. Laboratory studies of sediment settling characteristics and

evaluation of data from oxygen depression field studies indicated that the only detectable disturbance in the upper water column was due to the overflow immediately proceeding the release and the lifting effect of prop and hull interaction with the plume in the lower water column. Subsequent monitoring was confined to the lower portion of the water column and included water samples for suspended solids. Parameters that were not altered by the operations, e.g. pH, were dropped or reduced in importance in order to increase the sampling intensity of effected parameters.

Large scale tank tests were conducted varying the type of sediment, the volume of release and the depth and salinity of the receiving waters. The tank tests were used to define how the sediments were interacting with the water column. The studies also included field measurements of the sediment condition in the barge with a clamshell operation and in the hopper of the draghead suction dredge. Vessel vibration and the resulting vibration transmitted to the sediment were compared with laboratory settling and vibration studies of the sediments. The studies included how the type of sediment, the method of excavation and the transport affected the disposal plume.

The field monitoring was redesigned. The resulting system was a series of twelve pumps taking water samples for suspended solids at one-minute intervals from a three station cross-section of the lower water column anchored in the disposal and one down current station. Salinity, currents, temperature, dissolved oxygen and turbidity were monitored at the center cross-section station throughout the lower water column. Problems with interpretation of data led to small scale tank tests in which the interaction between two plumes was examined. The tests showed qualitatively the generation of higher density plumes, greater plume heights and secondary wave front. The field data (with knowledge of the two hoppers of the Dredge Harding) were explained by analogy to the tank tests.

Additional field work was done using other types of dredging equipment and disposal sites. A submerged pipeline disposal was similiarly monitored. Clayey sediment disposal from a clamshell operation was monitored in the ocean using a tethered vehicle for sampling, photography and on-deck video display. Sand disposal on the San Francisco Bar utilized a cross-section with samples and measurements made by divers. The parameters controlling the release pattern were the type of sediment, in terms of grain size distribution and liquid limit, and the sediment disturbance with the adding and mixing of water during the dredging operations.

The above parameters along with salinity can also be used to explain the variation in turbidity during the dredging operation. This has application in terms of both minimizing the potential environmental impacts and increasing the dredging efficiency. Major decreases in pumping rates occur as the bottom sediments are increasingly disturbed.

The second example concerns the chemical characterization study. The study had two major tasks - definition of the bonding of the various contaminants and determining the controlling factors which would affect release of contaminants. Rather than a cursory baseline type study, a limited number of samples were selected for detailed analysis.

Definition of the bonding utilized the progressive extraction scheme developed by Dr. Engler of WES. In general, the extraction identified the contents of interstitial water, exchangable, easily reducible, organic, moderately reducible and residual. For correlation with other study elements, grain size determination was accomplished under both dispersed and nondispersed conditions. Dispersed conditions relate to the chemistry of the contaminants where as the nondispersed conditions relate to how the sediments are perceived in the estuarine environment.

The sorption desorption work consisted of batch testing of a matrix of conditions. The conditions were sediment's metal, salinity, Eh, contact and sediment-water ratio versus temperature, pH, and water's metal concentration. The data were used to develop predictor equations which in turn were used to intrepret the results of field studies.

The interactive studies generally included both laboratory and field studies. The laboratory studies, by isolating causes and determining the trends or breaking points, provided both guidance in establishing the field studies and interpretation of field data. In the case of physical-biological interaction bentonite was used to evaluate lethal interaction of suspended solids, dissolved oxygen and temperature. Bentonite has similiar grain size distribution and shape characteristics as sediments from Mare Island Strait. The work was continued by WES using sediments from Mare Island Strait and Oakland Inner Harbor. In the chemical-biological interaction work, field studies were scheduled for two separate dredging cycles. Major rainfall coincided with each of the cycles - a perfect statistical correlation. Although initially the data was uninterpretable, it later proved to be valuable during analysis of what was occurring in the system when compared to the chemical-biological laboratory studies. In the subsequent field tests, rainfall and runoff were eliminated as variables.

Table 1 summaries the major reporting elements.

A wide range of expertise was represented in the study. More important was the ability of the individuals to continually re-evaluate their work in terms of specific objectives and the communication in the truest sense between the various study elements and other studies.

The greater understanding of what is happening during dredging and disposal operation means a greater understanding of other activities and processes in the estuary. Sediments moving in the system have generally been regarded as "pollutants". The evaluation of different aspects of our environment must look at their role in the environment. Sediments have an important and necessary role in the estuarine and ocean system.

Background for this paper is derived from the Dredge Disposal Study conducted by the San Francisco District of the Corps of Engineers. Publication of this paper has been approved by the Corps of Engineers, but the views are strictly those of the author. Special thanks is given to Mr. Thomas Wakeman whose editing lends some sanity to the paper.

TABLE I

MAIN REPORT - February 1977

The San Francisco District investigated the effects of dredging and sediment disposal on the marine environment of San Francisco Bay. The study was site and problem specific. Its scope included definition of sediment types, reaction of the sediments in the water column and on the bottom; the reaction of biological communities to dredging and disposal operations; and the availability of pollutants. Other study elements addressed the alternative disposal methods, dredging equipment and modified operations. The Main Report summarizes the various studies and interprets the results in defining the impact of dredging and disposal operations in San Francisco Bay. NTIS ADA 037 727 or ADA 038 308

APPENDIX A MAIN SHIP CHANNEL (San Francisco Bar) - June 1974

The report presents the results of studies conducted in 1971 and 1972 regarding the environmental impact of the disposal of fine sand from the Main Ship Channel on the San Francisco Bar about five miles outside the Golden Gate. Studies include sediment analysis, water quality monitoring, material dispersion evaluation and biological sampling and laboratory experiments. The studies centered on the dispersion of sediments by the U.S. trailing suction hopper dredge BIDDLE. NTIS ADA 038 309.

APPENDIX B POLLUTANT DISTRIBUTION - June 1979

The report presents an analysis of the horizontal and vertical distribution of contaminants in select areas of San Francisco Bay. Sedimentary processes in the Bay are described, previous samplings of contaminants in sediment are analyzed and the levels of contaimiants are discussed in terms of location, strata, sediment type and sources of contaminants. NTIS ADA 071 722.

APPENDIX C WATER COLUMN - April 1976

The report presents the results of field studies to determine the impact of dredging and disposal operations on water quality. Parameters measured were salinity, conductivity, temperature, dissolved oxygen, pH, turbidity and suspended solids. Special studies were conducted to quantify the sediment loading of the water column during both dredging and disposal and dissolved oxygen depression during open water disposal. NTIS ADA 038 310.

APPENDIX D BIOLOGICAL COMMUNITY - August 1975

The report presents sampling data on the infauna organisms in the Bay. Eleven stations were established in three project sites and four disposal areas. Five sampling periods over a period of one year were used to represent conditions ranging from high fresh water inflow in the winter to the dry period in late summer. Sediment and water samples near the bottom were also collected. Sediment sample parameters were temperature, pH, total sulfides, grain-size distribution and the heavy metals of

copper, cadmium, zinc, lead, and total mercury. Water samples three feet from the bottom were analyzed for temperatures, salinity, dissolved oxygen, pH, total sulfides and optical turbidity. NTIS ADA 037 728

APPENDIX E MATERIAL RELEASE - August 1977

The report presents the results of sediment circulation studies in the northern portion of San Francisco Bay. Work included the development of a numerical model and the conduct of a long-term tracer study using neutron activation methods. The tracer program used quantitative techniques to measure the vertical distribution of dredged sediments at select stations covering a 100-square mile area over a ten-month period. NTIS ADA 043 790

APPENDIX F CRYSTALLINE MATRIX - July 1975

The report presents the results of an investigation performed to ascertain the extent sediment-associated heavy metals may be made available to the biotic assemblage via release from the sediments. Laboratory characterizations of the sediments encompassed physical, chemical, and mineralogical parameters. The relative distribution of the several metals between the various sediment phases and by inference, the metal chemical species, were identified. Desorption experiments were conducted over the range of physical and chemical conditions expected to occur in dredging and disposal operations. NTIS ADA 037 542

APPENDIX G PHYSICAL IMPACT - July 1975

The report presents the results of laboratory studies on the lethal impacts of suspended sedi‚.nts on select macroinvertebrates and pelagic species. Initial sensitivity screening of San Francisco Bay species utilized commercial kaolin sediments. Four species were run with commercial bentonite varying and integrating levels of suspended solids, temperature, and dissolved oxygen at constant salinity. The ability of each species to survive burial was also studied. The response levels will be integrated with the results of Water Column Appendix C in the final report to provide an evaluation of dredging related suspended solids increases in the Bay. NTIS 038 311

APPENDIX H POLLUTANT UPTAKE - September 1975

The report presents results of investigations on the mode of pollutant uptake and the influence dredging operations have on the trace metal composition of resident species in project areas. The study, using both field and laboratory experiments, looked at heavy metal variation in the animals, the sediments and the water. Animals with varying feeding methods included benthic, intertidal and fouling organisms. Field stations were established in Mare Island Strait in connection with Federal navigation channel. Two consecutive dredging periods were studied with sampling prior to, during, and following the maintenance dredging. NTIS ADA 037 543

APPENDIX I POLLUTANT AVAILABILITY - October 1975

The report presents the results of an integrated investigation of the effects of a disposal operation on pollutant availability to local invertebrate fauna and of the pathways by which pollutants may be accumulated by invertebrates. The pathways examined included water, sediment and suspended particulates. Pollutants included twelve trace elements and chlorinated hydrocarbons. NTIS ADA 038 312

APPENDIX J LAND DISPOSAL - October 1974

The report presents the evaluation of the economic, technical and environmental feasibility of land disposal of dredged material from San Francisco Bay and development of an economic comparison model of various dredging methods and transport modes for different combinations of alternative land and water disposal systems. Studies included costing of dredging equipment and transport modes; mapping potential land sites around the Bay; and evaluating sites in terms of the physical properties of the sediments, site operation and site constraints. NTIS ADA 038 313

APPENDIX K MARSH DEVELOPMENT - April 1976

Many of the diked, low-lying areas around the peripheral of the Bay are suitable or could be suitable with limited sediment filling for the reestablishment of marsh. The report presents the results of laboratory studies on germination, the development of nursery stock and the conducting pilot planting program. From these studies feasible methods are evaluated for establishing marsh vegetation on Bay muds as a means to stablize intertidal sediment disposal. The potential of this alternative for developed sediment disposal within the Bay is evaluated in terms of area of potential marsh and volume available for sediment disposal. NTIS ADA 037 544

APPENDIX L OCEAN DISPOSAL - September 1975

The report presents the results of studies to characterize conditions along the 100-fathom line north of the established ocean disposal site beyond the Farallon Islands. Physical, chemical, and biological investigations were conducted in the lower water column and in the sediments utilizing sampling, photography and video tape obtained by the CURV III, an unmanned, tethered vehicle from the Naval Underseas Research Center. In addition, the deposition pattern of two barge releases were surveyed using the tracks of the CURV III. NTIS ADA 038 314

APPENDIX M DREDGING TECHNOLOGY - September 1975

The report presents the results of field studies and laboratory simulation studies to determine the parameters which affect the level of sediment disturbance in terms of the sediment release pattern during disposal and potential for sediment transport from the disposal site. Field studies were conducted on hopper dredge and clamshell dredge with barge. Laboratory simulation utilized silt and clay sediments from San Francisco Bay. In addition, several engineering aspects of land disposal

and intertidal (salt pond) disposal were evaluated. NTIS ADA 038 315

APPENDIX N - ADDENDUM - September 1978

The report is a collection of surveys and reports by various groups either within the Corps or under contract to the Corps. The subjects cover benthic macro fauna, infauna and epifauna at specific project sites sediment dispersion from submerged pipeline and sediment disturbance during dredging. NTIS ADA 061 142

# GREAT LAKES OPEN WATER DISPOSAL CASE STUDY

BY

PAUL V. LANG [1]

## INTRODUCTION

Since the mid 1960's there has been increased interest in Great Lakes open water disposal and its alternatives. Executive Order 11288, entitled "Prevention, Control, and Abatement of Water Pollution by Federal Activities," was issued on 7 July 1966, in furtherance of the purpose and policy of the Federal Water Pollution Control Act, as amended (33 USC 466).

To comply with EO 11288, on 22 November 1966 the Chief of Engineers authorized a study to determine the need for, and effectiveness of, alternate methods of dredged material disposal in the Great Lakes Basin. The study was conducted with the assistance of the Federal Water Pollution Control Administration (now the USEPA), and was coordinated with eight Great Lakes States and the Department of the Interior. In addition, the Corps engaged the services of an independent Board of Consultants, composed of representatives from several academic disciplines, for study assistance. Investigations conducted during the study included construction and operation of pilot diked disposal areas at Cleveland, OH, and Buffalo, NY, treatment of the dredged material, modifications to dredging equipment and operations, functional studies of the effects of open-lake disposal on lake ecology, surveys of possible alternate disposal sites at 37 Great Lakes harbors and connecting channels, including Ashtabula, OH, and an economic evaluation of benefits which might accrue from improved Great Lakes water quality. The study culminated in a 12-volume report entitled, "Dredging and Water Quality Problems in the Great Lakes." Volume 1, entitled, "Summary Report," was issued in June 1969. The volume contained 14 study conclusions including the following considered pertinent to this presentation;

a. "heavily polluted sediments from tributary streams when transported to the lakes either naturally or by dredging equipment must be considered presumptively undesirable because of their possible long-term effects on the ecology of the Great Lakes . . . "

b. "withholding all dredgings from the lakes could expect to reduce (1) total solids reaching the lakes by about eight percent, and (2) potential pollutants by the same general percentage as for solids."

c. "while the benefits to the lakes that would be derived by withholding polluted sediments associated with dredging are real, they are not measurable. Except for limited areas and temporary situations the resulting improvement in overall water quality would probably be undetectable under present conditions."

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d. "at the present time justification for a program of diked disposal of polluted dredgings can be based only upon public objectives regarding the quality of the Great Lakes and the resulting evaluation of presently intangible benefits."

Subsequently, on 15 April 1970, President Nixon sent a message to Congress asking for legislation to prevent the deposition of polluted dredged material in the Great Lakes. The legislation, as finally enacted, became Section 123 of the River and Harbor Act of 1970, PL 91-611.

Section 123 provides that the Secretary of the Army, acting through the Chief of Engineers, is authorized to construct, operate, and maintain contained spoil disposal facilities of sufficient capacity for a period not to exceed 10 years. These disposal facilities are to be established at the earliest practicable date, taking into consideration the views and recommendations of the Administrator of the Environmental Protection Agency as to those areas which, in the Administrator's judgment, are most urgently in need of such facilities.

The Federal Water Pollution Control Act (FWPCA) Amendments of 1972 established new evaluation requirements for the discharge of dredged or fill material into navigable waters. Under Section 404 of the FWPCA, the Corps was charged with specifying disposal sites, based on application of guidelines developed by the Administrator of USEPA in conjunction with the Secretary of the Army, acting through the Chief of Engineers. USEPA published Interim Final 404 Guidelines in the Federal Register on 5 September 1975. USEPA subsequently published Draft Final 404 Guidelines in the 18 September 1979 Federal Register which reflect the 1977 amendments of Section 404 of the Clean Water Act.

This presentation relates how the laws and studies described above have been interpreted and applied to maintenance dredging and disposal practices at a typical Great Lakes harbor. Ashtabula Harbor, OH, on Lake Erie, has been chosen as a typical Buffalo District case study where several USEPA harbor sediment pollution reclassifications have resulted in capacity requirement changes for containment facilities. More significantly, the reclassifications have prohibited the containment of any sediments since designation, design, and construction of any one containment site has never been accomplished, before another reclassification has invalidated that containment site's design capacity.

GREAT LAKES OPEN WATER DISPOSAL CASE STUDY

Ashtabula Harbor, OH, is located on the south shore of Lake Erie approximately 40 miles west of Erie, PA and 65 miles east of Cleveland, OH. The harbor is one of the principal coal and iron ore ports on the Great Lakes. The iron ore, which is received mainly from the Lake Superior or Labrador, Canada regions, is sent by rail to steel mills in the Pittsburgh-Youngstown area. The coal, which comes by rail from mines in Pennsylvania, West Virginia, and Ohio, is shipped to Great Lakes ports. These two commodities accounted for 11,000,000 tons, or 94 percent of harbor waterborne commerce, in 1977.

Ashtabula Harbor was built in stages by authorization of several River and Harbor Acts since 1896. The existing Federal project consists of a breakwater protected outer harbor, and an inner harbor, located on the lower 2.0 miles of the Ashtabula River. Since 1969, an average of 225,000 cubic yards of material has been dredged annually from Ashtabula's outer harbor and the lower .8 mile of the Ashtabula River, and deposited in Lake Erie at a 1/2 square mile area, located 2 miles northeast of the East Breakwater Light. This disposal area was established in the mid-1930's.

In 1971, the Corps began investigating confined disposal areas to contain dredged material from Ashtabula Harbor. This search was commenced in response to a USEPA decision that 100 percent of the material dredged at Ashtabula required containment. This USEPA decision was made in response to Section 123 of P.L. 91-611 and was based on pre-1971 bulk chemical data.

In April 1971 the Corps suggested use of an upland site west of Ashtabula in Saybrook Township, designated Site 1, for containment of all sediments dredged from Ashtabula Harbor. Site 1 was rejected by local interests because it was outside the corporate limits of Ashtabula and because Saybrook Township opposed its use. Saybrook opposition was based upon environmental concerns and belief that development would restrict future industrial growth.

The Corps subsequently proposed another upland area, Site 14, in Ashtabula Township. This site, located east of the harbor, was thought to be more acceptable than Site 1 because of exisitng chemical spoil areas already located in this vicinity. Site 14 was rejected however after Ashtabula Township and the owner of the Site 14 property, the Cleveland Electric Illuminating Company, opposed the site at a January 1973 meeting.

Following the public meeting, the Ashtabula City Council passed a resolution selecting Site 3 (located in the nearshore zone of Lake Erie, adjacent to the lakeward side of the U. S. East Breakwater). Preliminary approval to proceed with detailed design and environmental work on Site 3 was received from USEPA, Region V, Chicago, in February 1974 and the U.S. Fish and Wildlife Service and the State of Ohio in March 1974. In addition, USEPA reiterated their classification that 100 percent of the sediments were polluted and required containment, based on grab samples collected in June 1974.

These 1974 bulk chemical data were evaluated by the so-called "Jensen criteria" which were arbitrarily chosen dry weight concentrations of seven

parameters: volatile solids (VS, 6.0 percent), chemical oxygen demand (COD, 60,000 mg/kg), total kjeldahl nitrogen (TKN 1,000 mg/kg), oil and grease (O&G, 1,500 mg/kg), mercury (Hg, 1 mg/kg), lead (Pb, 50 mg/kg), and zinc (Zn, 50 mg/kg). The polluted concentrations chosen were not based upon scientific study of actual or potential biological availability or effects. The polluted concentrations also disregarded natural backgrond levels of constituents. Application of these criteria resulted in a "polluted-requires containment" designation for any zone represented by a sampling station where the polluted concentration of any one of the seven parameters was exceeded.

The 1974 analyses revealed that all seven parameters exceeded their polluted concentration at one or more of the four outer harbor and three river sampling stations. The zinc polluted concentration was exceeded at all seven stations.

Contracts for Site 3 design, (design capacity of 10 years) and EIS data collection were awarded in June 1974. Design and collection of baseline data for the Draft EIS continued until May 1975 when USEPA transmitted new sediment classifications to the Corps, based upon grab samples taken at 11 outer harbor stations in February 1975.

The 1975 data resulted in USEPA reclassifying most of the Outer Harbor sediments as being unpolluted and acceptable for unrestricted open-lake disposal. Since the reclassified unpolluted area contributed 65 percent of the average volume dredged annually, the design contract for Site 3 was terminated. Redesign at Site 3 for the reduced volume requiring containment over 10 years, 35 percent of the average volume dredged annually, was not considered economically feasible.

The 1975 reclassification was again based on the Jensen criteria as applied to bulk sediment chemical analyses. One station at the mouth of the Ashtabula River, exceeded the polluted concentrations for four of the seven parameters (COD, TKN, O&G, Zn) and the zone this station represented remained classified as polluted. Of the remaining 10 stations, 9 exceeded the polluted concentration for zinc. However, USEPA explained their unpolluted classification in a 1 May 1975 letter which stated: "The zinc values are typical of this region along the southern shore of Lake Erie, while the values of TKN may be attributed to the time of year we sampled. Also, the uniformity and distribution of zinc and TKN indicates that they are from natural sources. In any case, if a sample has one or two parameters which are slightly in excess of the guideline values but the remaining parameters are low, it is our policy to consider the sample acceptable for open-lake disposal."

Site 15, located along the breakwater protected shoreline, east of the river mouth, was next suggested by the Corps, in response to the 1975 reclassification, to contain the 35 percent of the annually dredged volume classified as polluted. This site appeared to meet all engineering, economic, and environmental requirements. However, objections from the U.S. Railroad Association and the city of Ashtabula in early 1976 resulted in removing Site 15 from further consideration. The concern was that Site 15 construction would compromise future port facility expansion.

In 1977 the local interests contacted the Corps and requested dredging in the Ashtabula River, above Fifth Street (upper 1.2 river miles of the Federal project). This area had not been dredged since the mid-1960's, because of decreased commercial usage above Fifth Street. The Corps then explored, with USEPA, the possibility of emergency dredging in the upriver area, with open-lake disposal, along with other alternatives involving containment on private lands adjacent to the river. USEPA refused to approve open-lake disposal of the material classified as polluted, and restrictions on use of private lands for permanent confined disposal prevented implementation of these alternatives. Thus the Buffalo District continued its search for a suitably sized containment area.

Another solution to the confined disposal problem at Ashtabula was presented to the local interests at a March 1978 meeting. The solution involved the construction of a temporary dike facility adjacent to the river (near the upriver terminus of the Federal project) to serve as a holding area with capacity to contain designated polluted material dredged in 1 year. After the polluted material was deposited and dewatered in the 1-year design capacity holding area, the sediment would be allowed additional drying before being truck-hauled to a permanent disposal area inland. This solution was satisfactory to local interests, as evidenced by their commitment to acquire the holding and permanent disposal areas, and was expected to be acceptable to concerned State and Federal agencies.

In June 1978 the Corps received another reclassification from USEPA based on grab samples collected in June 1977 at eight outer harbor and five river stations. This reclassification resulted in 95 percent of the harbor sediments being classified as polluted, and therefore requiring containment. This reclassification resulted in the temporary site, adjacent to the river, being undersized and therefore unfeasible.

The more stringent 1978 classifications were based upon bulk parameters not analyzed in 1975, namely PCB's (highest concentration was 7.68 mg/kg) and pesticides (one sample contained 11.6 mg/kg dieldrin while the other 12 samples contained less than .01 mg/kg dieldrin). Ironically, bulk concentrations of some parameters analyzed both years, TKN, ammonia, and phosphorus, decreased significantly and concentrations of all other parameters analyzed both years changed little. Moreover the 1978 reclassification did not recognize available data from the Corps Ashtabula Aquatic Disposal Field Investigation, part of the Dredged Material Research Program (DMRP). This investigation, conducted primarily during 1975 and 1976, studied and evaluated physical, chemical, and biological effects of hopper dredge open-lake disposal. In a June 1978 letter to the Buffalo District from the Waterways Experiment Station, it was stated that based on the results of the Ashtabula DMRP studies, open-water discharge of dredged material from the harbor or the river was an environmentally sound alternative to confined disposal.

It is emphasized here that the USEPA Region V 1974, 1975, and 1978 evaluations were based on what that agency felt were unacceptable impacts of open-lake disposal. However, USEPA made their evaluations based on harbor data alone, without obtaining comparative data from open-lake disposal and

reference areas. Therefore USEPA made evaluations of impacts to the open-lake disposal area without knowing what the existing lake conditions were. In addition containment of the sediments was dictated by USEPA without conducting an evaluation of containment impacts. Containment was therefore directed without a comparative study of containment versus lake disposal impacts.

The Corps and USEPA met in August 1978 to try and resolve the situation. At this meeting both agencies agreed to conduct bioassays with grab samples collected from the outer and inner harbors, and open-lake disposal and reference areas. Both agencies agreed on the bioassay procedure and evaluation criteria and further agreed that the bioassay contractor's containment or open-lake dipsosal recommendation would be decisive.

Dr. Bayliss Prater, then of Heidelberg College, conducted the 96-hour toxicity bioassays in September, 1979 with grab samples collected by the Great Lakes Laboratory of Buffalo, NY. The procedure involved a recycling bioassay apparatus using Hexagenia limbata Walsh, Daphnia magna Straus, and Pimephales promelas Rafinesque, as the test species. Each sample (13 harbor samples, an open-lake disposal area sample, and an open-lake reference station sample) was classified as being either non-polluted, moderately polluted, or heavily polluted, using the percent mortality of the test species (average percent of two replicates from each sample) as compared to the suggested pollution degree categories (0-10 percent mortality indicating non-polluted, 10-50 percent mortality indicating moderately polluted, and greater than 50 percent mortality indicating heavily polluted). Bioassays resulted in classification of six non-polluted stations (four stations in the Outer Harbor and two in the Ashtabula River/Inner Harbor), and classification of nine moderately polluted stations (four stations in the Outer Harbor, three stations in the Ashtabula River/Inner Harbor, and the open-lake disposal area and reference stations). When mortality of all three species was averaged, mortality at the open-lake disposal area and reference stations exceeded mortality at any of the 13 harbor stations. Dr. Prater concluded that "Based upon the results of the toxicity bioassay it is recommended that dredged material from Ashtabula Harbor may be disposed of in the selected disposal site in Lake Erie."

Corps and USEPA Region V representatives met again in Chicago, IL, on 1 December 1978, to discuss toxicity bioassay results. The Corps position at this meeting was support for Dr. Prater's recommendation as agreed to previously between the two agencies. USEPA generally agreed that the toxicity bioassay adequately addressed short-term lethal effects but indicated they considered additional bioaccumulation testing necessary, prior to dredging the Ashtabula River above Fifth Street bridge, to evaluate sublethal effects of open-lake disposal. USEPA also stated that bioaccumulation testing of suspect areas below Fifth Street bridge might also be necessary prior to proposed 1979 dredging. USEPA stated that their concern for additional bioaccumulation testing was primarily based upon high concentrations of mercury found in the sediments (maximum concentration of 1.8 mg/kg analyzed in 1977 samples), and data being analyzed then which indicated high concentrations of HCB's (hexachlorobenzenes) in fish collected at Ashtabula. After further discussion, the Corps agreed to cooperate on additional bioaccumulation

testing with the understanding that USEPA would write detailed collecting, storage, analysis, and evaluation procedures for the bioaccumulation testing. USEPA would submit these procedures to the Corps no later than Christmas 1978. This submission would include a list of contractors capable of conducting the collecting, storage, and analysis. The Corps would contract the work to be conducted utilizing the USEPA submission as the contract scope-of-work. It was emphasized and agreed that the USEPA "Christmas submission" must include detailed and exact evaluation procedures and criteria to be applied to the contractor's data. It was also agreed that the bioaccumulation testing and evaluation would be the last work necessary for the Corps and USEPA to mutually resolve the most environmentally acceptable disposal method of Ashtabula Harbor's sediments.

The USEPA recommended sediment bioaccumulation procedure was subsequently received by letter dated 26 January 1979, and reviewed by various Corps offices. Because of the apparent research and development nature of this procedure, as opposed to purely regulatory testing and evaluation, and because the submission did not include evaluation criteria as previously agreed to, it became obvious that resolution and agreement was not to be forthcoming in time for proposed CY 1979 dredging. The Corps subsequently issued 404 Public Notices dated 29 January and 13 February 1979, describing proposed plans to open-lake dispose 170,000 cubic yards of sediment dredged from below Fifth Street and 150,000 cubic yards of sediment dredged from above Fifth Street, respectively, during CY 1979. These notices followed an explanatory letter, dated 12 January 1979, to Mr. John McGuire, Administrator Region V, USEPA, in accordance with the agreement made at the 1 December 1978 meeting for early announcement of dredging plans.

In response to the Corps 12 January 1979 letter and 29 January and 13 February 1979 Public Notices, USEPA indicated major objections to the proposed CY 1979 dredging plans. They indicated opposition to open-water disposal of sediments from Ashtabula Harbor classified as polluted, considering this proposed action to be environmentally unsound. A February 1979 USEPA reclassification, considering toxicity bioassay data, and slightly modifying the previous June 1978 reclassification, resulted in 90 percent of the sediment being classified as polluted and requiring containment.

In response to the 29 January and 13 February 1979 Public Notices, the Ashtabula Port Authority requested a 404 Public Hearing which was subsequently conducted on 30 April 1979 in Ashtabula. This was followed by a 404(b)(1) Evaluation being sent to USEPA by letter dated 6 June 1979 which requested USEPA response by 2 July 1979. The 404 Evaluation concluded that after careful review of all available scientific information, open-lake disposal of Ashtabula sediments was environmentally acceptable.

USEPA Region V was aware the 404 Evaluation was forthcoming long before the 6 June 1979 mailing and they arranged to take core samples for bulk chemical analysis at five Ashtabula River stations above Fifth Street, and grab samples at the open-lake disposal and reference areas, on 6 June 1979. The Corps was provided samples from these same stations to conduct bioassays. The fact that USEPA took no samples in the Ashtabula River, below Fifth Street, and in the Outer Harbor, was an indication that they were contemplating reclassifying that area again as unpolluted.

Dr. Prater of Aqua Tech Environmental Consultants Inc. conducted the bioassays with the same procedure and evaluation criteria utilized for the September 1978 test. The bioassays conducted with the core samples resulted in three of five river stations being classified as heavily polluted (top and bottom halves of cores were analyzed separately by two sample replicates but either half being classified heavily polluted resulted in the zone represented by the core length being designated heavily polluted). The open lake disposal and reference stations were again classified as moderately polluted. Thus, Dr. Prater recommended that all material dredged from the Fifth Street Bridge upriver to the mouth of Fields Brook (.4 mile from the upriver terminus of the Federal project) be contained. Areas dredged from below Fifth Street Bridge and above Fields Brook were again recommended for open-lake disposal.

By letter of 5 July 1979 the USEPA provided the results of their bulk chemical analysis of the core samples and also another reclassification. Based upon analyzed concentrations of PCB's (84 mg/kg max), HCB's (29 mg/kg max), and Hg (3.4 mg/kg max), USEPA objected to open-lake disposal of sediments dredged from Fifth Street upstream to the turning basin (.4 mile from the upriver terminus of the Federal project - the same river mile point as the previously mentioned Fields Brook mouth). While not objecting to dredging and open-lake disposal of material from the turning basin, they requested that this work be kept to a minimum. Material to be dredged above the turning basin, and open-lake disposed, was not objected to. Finally, material proposed for dredging and open-lake disposal during 1979 from below Fifth Street was not objected to. However, approval of open-lake disposal for material dredged below Fifth Street in future years is subject to further testing. This restriction is based upon concern of polluted material migrating downriver in future years.

Dredging plans above Fifth Street, during 1979, were modified to remove only 17,000 cubic yards in the shoaled turning basin. The remaining areas above Fifth Street generally had minimum water depths of 6 feet, which users stated was barely acceptable. Dredging below Fifth Street was accomplished during 1979 as stated in the public notice.

Two meetings were held on 21 August and 28 November 1979 between the Corps, USEPA, State of Ohio agencies, and local interets to resolve a long-range solution to dredging and disposal operations at Ashtabula. At the November meeting, USEPA offered local interests free consulting services to locate, design and environmentally evaluate alternative private upland sites for containment of all sediments designated polluted. The local interests accepted this offer and the work is currently underway.

This chronology has described the work and frustration encountered in trying to attain the soundest environmental solution to dredging and disposal practices at one Great Lakes harbor. This case study is still unresolved after 9 years of effort and it is only one of many Buffalo District harbors where similar situations exist. In addition harbors where containment areas have been constructed are approaching their 10th year of filling, when the containment versus open-lake disposal question must be wrestled with again, provided containment authorization is extended.

Clearly, valid scientific analysis and evaluation procedures are needed to make long-term environmentally sound 404 disposal decisions that are mutually acceptable to the Corps and USEPA. Hopefully, the long-awaited USEPA final 404 regulations and testing package will provide the needed guidance.

# RIVERINE CASE STUDY - COLUMBIA RIVER

BY

ROBERT J. HOPMAN*

INTRODUCTION. A concept of placing Columbia River dredged material in water near the channel has been developed with the idea there would be less adverse impact on uplands, wetlands and aquatic life forms and the associated fisheries. Flow-lane disposal or flow-lane dispersion are the terms used to refer to this concept. This article discusses this concept while offering an assessment of several in-water dredged material disposal operations on the Columbia River - not just one disposal operation in a riverine system as the title might suggest. Placement of clean dredged materials - classified as unpolluted by EPA standards - into strategically selected areas near the channel's edge might help resolve some of the previous chronic disposal problems while causing less damage to the aquatic resource and still retain the sediment in the river system for eventual ocean shoreline accretion. The concept is favorably accepted by the region's resource agencies. Perhaps we made effective forensic use of a tactic that is drilled into every dredging engineer's head: Emphasize the anti-in-water side's inability to offer alternatives.

COLUMBIA RIVER. From its headwaters in Southeastern British Columbia, the Columbia River and its tributaries drain the States of Washington, Oregon, Idaho, Montana and small areas in Nevada, Utah and Wyoming. It drains 259,000 square miles, about 15% of which are in Canada, on its 1,200 mile journey to the Pacific Ocean. The mean annual runoff is approximately 180 million acre-feet, almost 24 times the annual runoff of the Potomac River.

Importance. The river system provides water for a variety of uses, including power generation, irrigation, fisheries, recreation and navigation. The following overview may provide some valuable insights.

- In 1979, more than 125,000,000 megawatt hours of hydroelectric power were generated by the dams on the Columbia system. This is equivalent to 200,000,000 barrels of oil. Each barrel of oil has a consumer value of about $40.00. If the hydroelectric plants had not been constructed, it would have cost $8 billion dollars to generate this power with oil.

- Approximately 7 million acres of agricultural land in Oregon, Washington and Idaho were irrigated with water from the river system in 1979.

- Fisheries in the Columbia basin produced $20 million worth of commercial fish products during 1978.

- More than 45 million tons of freight were moved during 1977 on the Columbia River system from the Pacific Ocean to Lewiston, Idaho, a distance of 465 miles. Tugs and barges are raised a total of 738 feet in this distance by single lift navigation locks at eight multiple-purpose projects.

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- In 1979, the Corps' Northwest projects provided over 15.2 million recreational days, of which the major part were on the Columbia River system.

Dimensions. The navigable length of the Columbia River extends from the Pacific Ocean, with a 48' deep by ½ mile wide channel at the entrance bar, 105 miles to the Portland-Vancouver area where authorized deep draft dimensions are 40' X 600'. The remaining part of the Columbia and Snake River system is a barge channel with authorized depths varying between 14' and 27' and widths between 250' and 300'.

This study considers only the lower 105 mile stretch of 40' x 600' river channel. It would seem, however, that the conclusions could be considered suitable in most aspects for the other sections without further extensive studies.

Normal Dredged Material Placement Program. Dredging on the Columbia River is accomplished by different types of conventional dredges.

Bucket/Clamshell Dredge. This type of dredge consists of a bucket or clamshell operated from a derrick mounted on a barge. It is used extensively for removing small volumes of material. The sediment, removed at nearly its in situ density, is usually placed in barges or scows for transportation to the disposal area, generally a specified in-water site if the material is unpolluted. Records show that in the last 50 years, about 5 million cubic yards of material have been bucket dredged and placed into designated open-water disposal areas.

Cutterhead Dredge. This dredge, getting its name from the rotatory cutter at the end of a ladder for excavating the bottom material, is quite common on the Columbia River system. The excavated material is picked up and pumped through an 8 to 36-inch discharge line as a slurry with a typical solids content of 10 to 20 percent by weight. The material is pumped by a centrifugal pump to a disposal area. Disposal areas are located from 1,000 to 20,000 feet from the dredging area. Cutterhead dredge material can be placed on upland sites behind dikes to supply landfills and for recreational development and commercial use. This material is completely removed from the system and, in some aspects, this is unfortunate. It is estimated that, in the last 50 years, 300 million cubic yards of clean, fine to medium grain sands have been disposed of in this manner. The remaining cutterhead dredged material, estimated to be 150 million cubic yards, has been placed back in the system in open-water sites, behind and alongside permeable groins, or used for formation of beaches, beach restoration purposes, or creation of islands for goose-nesting purposes.

Hopper Dredge. The hopper dredge is compared to a large vacuum cleaner because of its capability to hydraulically lift bottom materials up through trailing suction pipes and temporarily store them in hopper bins in the ship's hull before they are emptied into designated in-water dump sites. The hopper dredge is self-propelled and is capable of working in those areas characterized by heavy ship traffic or rough entrance bars. During the last 50 years, about 340 million cubic yards of bottom sediments, primarily from maintenance operations and evaluated as uncontaminated, have been hopper dredged and placed back into open-water sites in the Columbia system. If this material were

stacked onto a football field, the pile would be nearly 40 miles high. Fortunately, there are now ample research results indicating that the traditional fears of water quality degradation resulting from the resuspension of dredged material during dredging and disposal operations are, for the most part, unfounded. In most cases, the environmental impact associated with the dredging of uncontaminated sediment will be insignificant.

FLOW-LANE DISPOSAL CONCEPT. This concept or method of disposing clean, uncontaminated Columbia River sand is no tumultuous incident. It simply consists of discharging the dredged slurry into pre-selected in-water sites where the hydro-dynamic regime is technically considered although non-technical factors sometimes outweigh technical ones, however, usually more as a rule than as an exception. It's an exploitation of nature required to demonstrate its viability.

Flow-Lane Disposal Areas. We have limited flow-lane disposal operations to a very few locations on the Lower Columbia River because the endless number of complex hydrological variables of this technique have not been completely studied. Literature on related subjects is abundant, however, although the views expressed are by no means always in concordance with each other. Accordingly, because of the high degree of variability associated with different environmental and operational parameters and the many phenomena associated with this technique which can only be considered qualitatively as based on field observations, we confined its extent generally to the same bar or reach of river and depths of water.

Same Bar. Most of the material dredged on the Columbia River has in-place densities ranging from 1,700 to 2,000 grams per liter and has been dredged from 26 bars or perennial shoaling areas. Several reasons, cited below, exist for the decision to limit dredging and disposal to the same reach of river.

- Depending on the nature of the material, a drastic habitat change could occur when the disposed sediment is quite different from the existing bottom, as, for example, when fine material is placed on coarse sand or vice versa.

- Bottom topography that was believed to be somewhat immune to erosion was selected. Following disposal, material may remain in place for a long period of time or may undergo relatively rapid erosion and dispersion. Which event or combination of events that occur depends on the nature of material, bottom currents or stretch of river. These events are influenced, of course, by depth and the adjacent subaqueous topography. Hopefully, in part, through some intuitive engineering and after-the-fact field monitoring, we have selected sites where the mound of bottom deposits is predicted to slowly erode during a period of one to five years. Recognizing this fact is important because it is one of the determining parameters effecting the quantity to be deposited. The potential impact associated with rapid erosion could add to a high degree of turbidity and suspended particles that could clog gills and feeding apparatus of some bottom dwelling invertebrates. In addition, it could effect the pelagic community. (This community consists of plans and animals which have low mobility and which tend to drift with currents.)

- Studies by the Portland District and later substantiated by the Dredged Material Research Program (DMRP) have concluded that, with few exceptions, the physical effects of dumping clean dredged material in open water are more important than chemical or biological effects. 5/ The smothering of benthic invertebrates or disruption of a flow pattern are examples of physical effects. When avoiding these particular areas, other areas considered to be naturally stressed, because normal environmental conditions are variable rather than stable, were selected. Organisms which occur under such conditions are generally able to better withstand any stress associated with the disposal operation and recover more rapidly than those in stable environments. In other words, we did not want to chance any environmental damage should our studies be wrong because the consequences of disposal operations are persistent, often irreversible, and may be compounding.

Depths of Water. Our studies show that in 20 to 40-foot depths of water, an estimated 95% of the fine to medium grained Columbia River sand from a typical open water flow-lane disposal operation descends rapidly through the water column and impacts on the bottom. It forms a low gradient fluid mound overlying the existing bottom sediment. The greater part of the remaining small percentage of fine-grained material is dispersed in the water column as a turbidity plume. We found that depth of water is an important parameter, from a practical point of view, that can be determined to effectively control the characteristics and mitigating occurrences of dispersion. Perhaps more than in any other alternative, successful disposal of the material or use of the flow-lane sites for recovery of the natural resource requires favorable and often fortuitous circumstances. This did occur. Therefore, disposal into 20 to 40 feet of water is of utmost importance.

- Studies have shown, in addition to importance to benthic communities, water depths of less than 20 feet in the Columbia River are critical to juvenile and adult salmonoid migration routes. Reasons for this may be that high current velocities are less here than in other parts of the river requiring less effort for fish movement; bottom dwelling communities and food chain production and nutrients are likely to be more dense than in other parts of the river, undoubtedly leading to fish attraction; and bottom topography may afford added protection from predators.

- Impacts on the bank fisherman are just as important as the reasons cited above for fish. A bank fisherman adorning hip boots and utilizing a hefty heave with an 8 to 10-foot fishing pole, is able to cast his line into depths of about 15 to 20 feet. In his mind, this is the sacred depth of water where, in the past, he has caught many large salmon weighing 40 pounds or more. In-water disposal into his section of river could disrupt current flow patterns or water temperature and possibly alter fish routes around the mounds of deposits. Ultimately, this could lead to reduction in fish catches making a very unhappy segment of our society.

- Twenty to forty foot depths at selected sites seem to partially satisfy one criterion that deposits should slowly erode over an extended period of time.

In depths greater than 40 feet, mound deposits often erode away too quickly. It has been shown that materials dumped into deep water or "energy" holes never accumulate into lasting mounds but scour away due to intense currents near the bottom. Apparently, the currents are sufficiently high to transport appreciable quantities of dredged material out of the site before they can be deposited on the bottom. Therefore, it becomes difficult, although not impossible, to predict the ultimate fate of the dredged materials and thus we lose the capability to corral this natural resource for productive purposes.

- The operational factors of dredged material dispersal are easily and safely accomplished by the different types of conventional dredging equipment on the Columbia River. The 20 to 40-foot depth constraint can satisfactorily be met. When necessary, operational procedures can be safely varied to effectively control and achieve any desired dispersion characteristics.

- The slope of the bottom probably has the greatest influence on the flow traits of low-density fluid headwave of bottom deposits - more so than the effects of current, indicating that gravity is the controlling force in the movement of the deposits. For example, if the bottom has a sufficient downslope, the velocity of the flowing headwave will increase until accurate prediction of thickness, shape and predominant direction of dissipation is very difficult. Through extensive hydrographic surveys, we satisfy the necessity of gentle slopes for proper dispersion of dredged materials.

- Benthic communities and organism abundance are more prevelant in shallow waters. Disposal does effect the benthic community, probably by burial or smothering, but the ecological significance of the effects is not clear. Nonetheless, we chose not to aggravate Columbia River waters and associated bottom life with flow-lane disposal operations in depths of less than 20 feet.

- Finally, studies and field monitoring indicate that if problems are to occur regarding precision placement of dredged material into open water sites, they will probably happen in deeper water. 8/ Other researchers have observed that the upper portion of the water column extending from 25 to 35 feet below the surface was uneffected by the dumping operation. Accordingly, knowing it is important to have, in addition, at least a conceptual understanding of how dredged materials behave when dumped into flow-lane disposal sites, we have presumed that sediments will have less of a real or imagined deleterious effect on the aquatic life forms if placed in waters shallower than 40 feet or greater than 20 feet.

STUDY RESULTS. The following portion of this article briefly synthesizes the results of two research studies recently conducted on the Columbia River. Each study will be briefly described and the findings summarized non-technically. Those desiring more specific information are encouraged to consult the selected bibliography.

1. Impact of Flow-Lane Disposal at Dobelbower Bar. 1/ This study was conducted during 1975 and 1976 by the National Marine Fisheries Service, (NMFS) under contract to the Portland District, Corps of Engineers. Difficulty in locating new traditional-type disposal sites in the Dobelbower Bar stretch of the Columbia

River near Longview, Washington prompted a search for different means of disposing of the dredged material. Personnel of the NMFS suggested that placement of the dredged material in a self-scouring area in or near the channel might help resolve some of the disposal problems. They also indicated there were fewer benthic life forms in the channel area of the Columbia River, particularly the self-scouring areas and the areas where there is enough river traffic to keep the bottom sand active. To test the concept, the Dobelbower dredge study was developed to examine the extent of the turbidity plume, distribution of the dredged material, and impact on the aquatic life forms resulting from in-water disposal.

The study had the following objectives:

1. Monitor the extent and concentration of turbidity created by dredging and disposal.

2. Assess the impact of the dredging activities on water quality, zooplankton, and benthos, and,

3. Determine the retention time of the dredged material that was "windrowed" at the site.

The procedure was to collect data before, during and after the dredging operation and use this information to form the basis from which comparisons could be made to assess overall impact. Results and conclusions were:

1. Turbidity in the Columbia River during the dredging effort did not exceed 30 JTU's whereas, at times natural turbidity during the monitoring time exceeded 70 JTU's.

2. Turbidity levels during dredging and/or disposal apparently had little effect, if any, on finfish or shellfish.

3. Nonfilterable residue increased with increasing turbidity.

4. There were no long-term effects on those water quality parameters measured near the dredge and disposal operations.

5. The dredging operation did not noticeably alter zooplankton abundance or diversity.

6. The majority of benthic variations between sampling times (before, during and after dredging) and sampling area (control, dredged, and disposal) can be attributed to seasonal variation and station location rather than a primary effect of the dredging operation.

7. The entire Dobelbower Bar area is relatively low in benthic production when compared with the estuary and slough areas of the river.

8. The material deposited in the flow-lane was dissipated within approximately one year.

2. Biological Impact of a Channel Widening Project Near Pillar Rock. 4/ This study was conducted during the winter of 1977 by the NMFS under contract to the Portland District. Approximately 600,000 cubic yards of sediment from the Pillar Rock Bar (river miles 27 to 29) were dredged during this study. The effects of cutterhead dredging as well as the in-river (flow-lane) sediment disposal on economically important finfish and benthic food organisms was unknown in this area. Therefore, the Corps and NMFS believed a biological study of this project would assist all agencies evaluating future projects of a similar nature in this estuarine area (river mile 22 to 35). The study of dredging and disposal effects was designed to include those particular aspects that had not been examined in the earlier study at Dobelbower Bar and the Propeller Wash Agitation Dredging studies of Chinook Channel, Washington.**

Results and conclusions were:

1. The impact of pipeline dredging at the dredge/disposal site on pelagic species was apparently minor.

2. Dredge or disposal related impacts on the weight changes of captured finfish was not great.

3. Bottom sediments can be considered clean sand at all areas surveyed during the study.

4. Based on hydrographic surveys, the flow-lane concept of disposal resulted in sediment movement as predicted.

5. With the exception of turbidity, there is not a significant difference between water quality values collected at the surface and near the bottom during the study.

**The Propeller Wash Agitation Dredging, Chinook Channel, Washington study was undertaken in 1976 to evaluate the economic and environmental feasibility of propeller wash dredging using a large vessel equipped with an adjustable deflector door. The study included the collection and analysis of hydrographic surveys; tide and current data; sediment samples; water quality, salinity, temperature and turbidity measurements; aerial photographs of plumes; biomass and species counts; and dredge records of operation and movements. Data collection included pre-dredge, dredge and post-dredge phases. Physical and biological monitoring was limited to the general vicinity of dredging and biological sampling was confined to aquatic, epibenthic and benthic macroorganisms of that area. Corps of Engineers, National Marine Fisheries Service and contractor personnel participated in the study. Propeller wash dredging was accomplished by the SALVAGE CHIEF, a seagoing tug owned and operated by Fred Devine Diving and Salvage, Inc., Portland, OR. The SALVAGE CHIEF is a converted LSM, modified primarily for the purpose of freeing grounded vessels. A large "S" shaped door (22 feet wide and 20 feet long), controlled by six hydraulic cylinders is mounted on the stern for excavation work. The door deflects propeller wash away from twin 55-inch diameter propellers, creating a scouring flow which hydraulically excavates bottom material lying immediately astern of the vessel. The SALVAGE CHIEF is a 192-foot twin screw vessel with 1,800 horsepower at 600 RPM on each shaft. The 7 to 8-foot draft vessel is equipped with lines and winches for a six point anchor mooring system.

6. Conductivity did not vary significantly.

7. Increased turbidities were directly related to high flow conditions in the Lower Columbia River during November and December. These higher turbidity values probably overshadowed any subtle changes that were the result of the dredging operation.

8. No significant differences occurred in dissolved oxygen levels.

9. Dredging and sediment disposal during late fall and early winter months probably affected invertebrates less than had the dredging occurred during other times of the year.

10. Sediment removal in the dredge area did not appear to change the bottom composition.

Other Columbia River studies have been conducted in recent years to determine the effects of in-water disposal operations. For sake of space, I am not going to discuss these studies now but results are available in the North Pacific Division office.

FLOW-LANE DISPOSAL IS ENVIRONMENTALLY SOUND. Making such an overwhelming statement appears, on the surface, to be inviting a squabble from those who hold that "dredging" is a dirty word and is on the opposite end of the one to ten rating scale from "environment". However, disposal of dredged materials, especially into water does not have to be associated with the household word "pollution". The term, "environmentally sound" is then a qualified statement and is used only when the dredged materials are classified as clean sands according to EPA standards. To put the hard line environmentalist's mind at ease, for each dredging project, the Corps considers all likely alternatives to the disposal of dredged materials by open-water dumping. In many instances, however, there is no environmentally or economically suitable substitute for in-water disposal. I will analyze this bold grandaddy statement.

Prevents Erosion. Placement of dredged materials into strategically selected flow-lane disposal areas can prevent erosion to banklines, islands and the river bed itself. Scour of the river bottom sediments and erosion of the bankline creates a very real, long-term disruption to aquatic life form. In addition, it introduces substantial suspended sediments and turbidity to the river system which can degrade water quality. Economically, erosion also can prove to be disasterous to expensive real estate normally found along the banks of the Columbia River.

As mentioned earlier, an important criterion of flow-lane disposal operations is the proper placement of dredged materials in strategic locations in order that dissipation of the humps or mounds occurs slowly where the bottom current is low, perhaps 0.1 ft./sec. or less. Sacrificial erosion of the artificial humps will surely take place and will contribute to replacement of downstream bankline or river bottom sediments that are naturally eroding away. This is the phenomena of scour and deposition. The control of this process lies in the seasonal sediment budget of the reach; so long as the supply of appropriate sediments is deficient, the flow may continue to make up the deficiency.

The normal process of erosion may be further aggravated by the dredging operation that removes sediments from the system by placing them on upland sites. Simply stated, for every cubic yard of sand removed from the system at a given period of time, a cubic yard of sand is thought by some - and could very well be the case - to be entrained (eroded) from the bed or bankline to bring the system back into near equilibrium.

Most rivers will establish a regimen which is practically in a state of equilibrium so far as general channel conditions, depths, and cross-sectional areas are concerned. The sediment reservoir on the bed of a river can be a very thin layered system containing the river's greatest number of benthic organisms. This thin top layer of bed sediment is also most sensitive to shear stress. When shear stress in this layer exceeds the critical shear stress for mass erosion, that layer fails and immediately becomes a sediment source for possible entrainment. Therefore, any interruption to the river's sediment budget by dredging and removing sand from the system would tend to scour sands from the easily erodible top layer in order to bring the river back into equilibrium. (Of course, this is true only if by dredging the tractive force becomes out of balance with other river characteristics.) Accordingly, by not removing the materials from the system flow-lane disposal will contribute to the welfare of bottom organisms dwelling on and in the critical top layer of sediments by providing a dampening effect to the inevitable erosion process.

Is There an Endless Supply of Sediments or Not? I have been talking about sediments without regard to supply of sediments - perhaps on purpose because the subtleties of sediment yield within the channel are not yet clearly understood. I propose, however, that the supply of sediments is not endless and, if possible, dredging materials should not be placed onto upland sites or certainly be kept to a minimum because of this fact.

A primary purpose of some dams is to provide storage of flow during periods of highwater - for use during periods of low flow. The reduction of floods by storage decreases the devastating waters that cause river bank and overland erosion which in the past, prior to dam construction, added to river sediments.

In addition to creating changes in flows, dams with large storage capacity trap virtually all of the sediment that previously passed through the reach in which the dam is located. Some, researchers estimate the amount of material trapped behind dams is a most ominous statistic - about 95 to 99% of total sediments in motion. 7/ Since the source of shoaling material originates below the Columbia River dams in a relatively short length of river as compared to a total length of river of about 1,200 miles, placement ashore of all dredged material could some day deplete the main source of these sediments from within the river system itself.

Submerged Groin. I suggest that flow-lane disposal could produce material for temporary submerged groins. Channel constrictions, whether combined with the dredging operation or not, have been effective in establishing and maintaining appropriate channel depths in the Columbia. Such constrictions often take the form of groins projecting out from banks, particularly in bends, to

control the flow pattern. For an unsubmerged constriction, all the flow passes through the constriction with an increase in velocity and slope which erodes the bed to a lower elevation. At high flow rates, the resultant scour may be excessive and produce some unwanted channel shoaling elsewhere. Therefore, it is suggested that submerged constrictions would alleviate excessive scour, since for large discharges, a considerable portion of the flow passes over the submerged groin and thus does not contribute to the sediment transport capacity. 3/ The selection of the submerged groin geometry is best accomplished through trial and error methods or in the case of the Columbia River, through mathematical or available hydraulic models.

The effectiveness of a submerged groin in providing increased water depth, although temporary, without the normally required dredging and disposal operation may some day prove exciting both as a means of reducing channel maintenance costs and lessening environmental concerns associated with dredging operations.

CONCLUSIONS. I have just given you a plausible concept dealing with the placement of clean dredged sands into water at selected sites. This is called the flow-lane disposal concept. The fundamental characteristics of the river corridors within each physiographic section should always dictate the type of disposal strategy which will be appropriate to use to preserve a river. Accordingly, certain sections and river corridors are more amenable to certain strategies than others and no one disposal approach is suitable nationwide.

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DREDGED MATERIAL DISPOSAL CASE STUDY
MILITARY OCEAN TERMINAL, SUNNY POINT, NORTH CAROLINA

By

Christina C. Meshaw[1/]

## INTRODUCTION

The Military Ocean Terminal, Sunny Point, North Carolina, is located on the Cape Fear River about 6 river miles upstream of Southport, North Carolina, and about 12-1/2 river miles downstream of Wilmington, North Carolina. The Sunny Point terminal is used to transfer military cargo from land based transportation to oceangoing carriers. It is operated for all the armed services by the Army's Military Traffic Management Command. The Sunny Point facilities include a mooring area along the Cape Fear River that allows six vessels to be loaded simultaneously. The average cargo ship requires a draft of 28 to 34 feet. Shoaling of the access channels and basins has averaged 1.8 million cubic yards annually, and dredging has generally been needed on a biannual basis.

From the completion of the Sunny Point terminal in 1955 until 1971, standard practice was to dispose of dredged material in open water. When the National Environmental Policy Act of 1969 took effect, other Federal and State agencies refused to allow further open water disposal. Their refusal was for two reasons:

1. There was a reduction in depth of fish and shrimp nursery areas over a period of time such that, in the opinion of the other agencies, the thermal regime of the areas was making them unsuitable for nursery areas due to heat stress.

2. The impacts of suspended sediments and other pollutants were detrimental to aquatic life.

As a result, the Wilmington District undertook a program to provide two diked upland disposal areas having a combined capacity of 28.5 million cubic yards of dredged material and a life expectancy of 15 years, for the Military Ocean Terminal, Sunny Point. Disposal area 2 (see map 1) was built in 1972 and used for dredged material disposal in that year and again in 1974 and 1975. During these disposal operations, a high hydraulic head was maintained on disposal area 2 by retaining the slurry water to maximize the quality of the effluent leaving the disposal area. Disposal area 4 (see map 1) was completed in 1977 and has not yet been used for dredged material disposal.

As shown on map 1, Sunny Point is bounded on the east by the Cape Fear River and on the north by Orton Pond. Orton Pond is part of the Orton Plantation complex, which is on the National Register of Historic Places. A finger of Orton Pond, called Tom Branch, drains north away from disposal area 2. There are also

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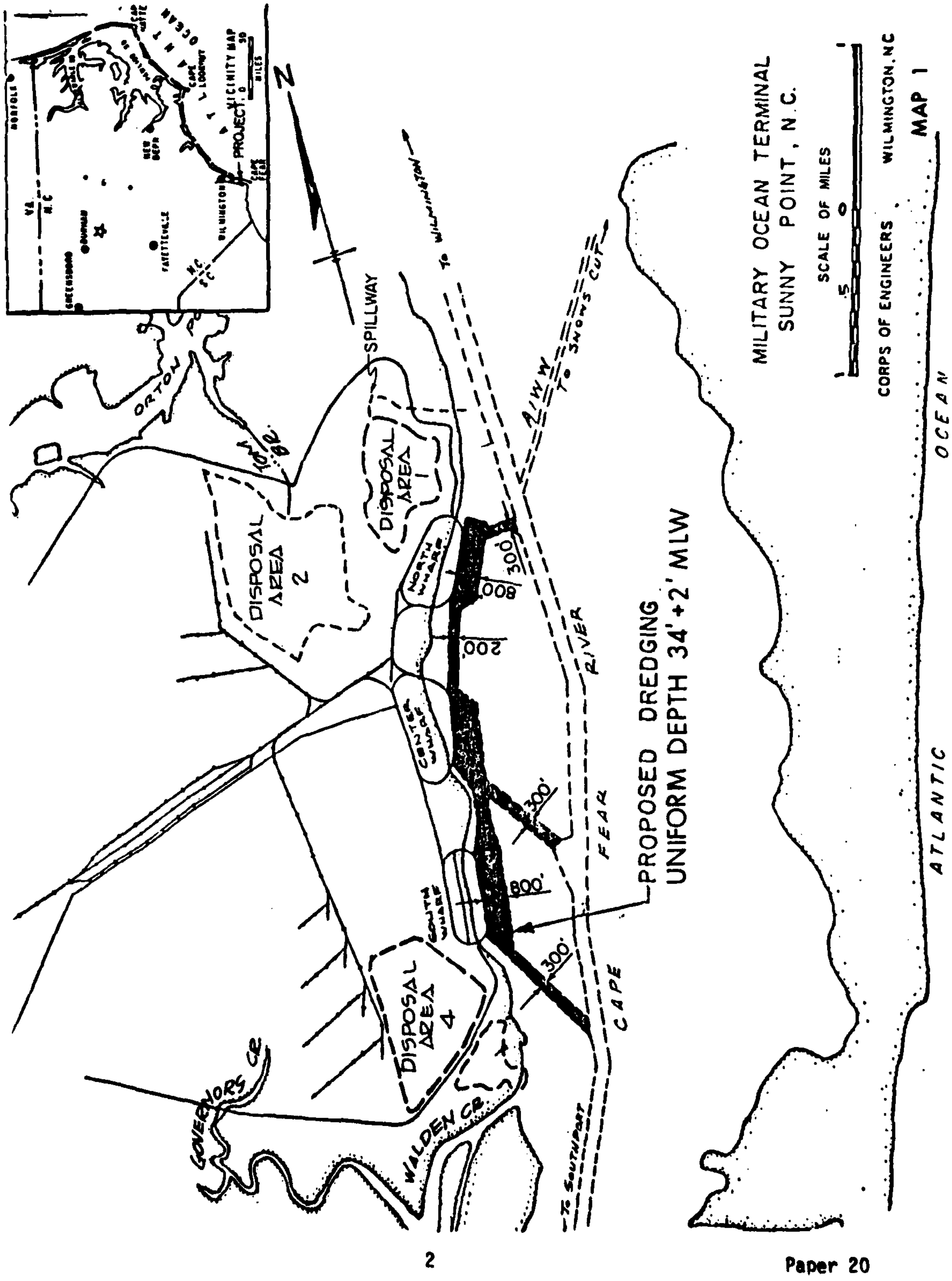

MILITARY OCEAN TERMINAL
SUNNY POINT, N.C.
SCALE OF MILES
5
0
CORPS OF ENGINEERS
WILMINGTON, N.C.
MAP 1
PROPOSED DREDGING
UNIFORM DEPTH 34'+2' MLW
ATLANTIC
OCEAN
CAPE
FEAR
RIVER
DISPOSAL AREA 1
DISPOSAL AREA 2
DISPOSAL AREA 4
NORTH WHARF
CENTER WHARF
SOUTH WHARF
SPILLWAY
ORTON
GOVERNORS CR.
WALDEN CR.
AIWW
TO SNOWS CUT
To WILMINGTON
To SOUTHPORT
300'
800'
200'
300'
800'
300'
N
VICINITY MAP
PROJECT

approximately 59 small freshwater ponds located throughout the military reservation. Many of the ponds are limestone sinks - depressions formed through subsurface solution of calcium carbonate. Six distinct zones of vegetation can be seen in the Sunny Point ponds: (1) shrub fringe, (2) ecotone, (3) cypress ring, (4) hydric zone, (5) central unvegetated zone and (6) central stand (of either pond cypress or blackgum).

## CASE STUDY

In 1977 the U.S. Army Environmental Hygiene Agency Environmental Assessment on the Sunny Point installation reported high chloride concentrations (100 ppm and up) in several monitoring wells near disposal area 2. Since disposal area 2 was constructed in an area of numerous limestone sinks, the possiblity that saltwater intrusion might occur as a result of dredged material disposal was recognized in the environmental impact statement filed with the Council on Environmental Quality (CEQ) in 1972; however, the possibility was discounted for two reasons:

1. Disposal area 1 (see map 1) was used in the original construction of Sunny Point without any readily apparent ill effects from saltwater intrusion.

2. The material dredged from the access channels and basins is a fine silty material, and it was thought that the material would act as a seal and prevent any saltwater seepage into the groundwater; however, saltwater intrusion did occur, and when it did, it damaged many of the freshwater ponds in the vicinity of disposal area 2. The most visible symptom of damage in the ponds is dead and/or dying vegetation from rooted aquatic macrophytes to cypress trees.

To determine the extent of saltwater intrusion and to monitor its movement, 58 wells were drilled in and around disposal area 2 during 1977 and 1978. These wells, together with about 54 surface water sampling locations, including Tom Branch of Orton Pond, are sampled on a monthly basis. Surface water sampling locations are sampled at surface and bottom depending on depth. Initially wells were sampled only at the surface but are now sampled at several depths due to vertical stratification. Chloride concentrations are determined on each sample since chloride is a saltwater tracer. Conductivity of each sample is measured as a check on the consistency of chloride concentrations. Water surface elevations are measured at surface water and groundwater sampling locations.

Chloride concentrations are determined in the District laboratory and the South Atlantic Division laboratory. Quality control measures include routine (known) duplicates within a lab, split samples between labs, unknown duplicates between labs and analyses of identical standards by both labs. You might ask why all the quality control for such a simple determination. The chloride determination is a simple analysis, although the endpoint is difficult to see and we have had problems with lack of agreement between labs. My point is that quality control cannot be ignored in water quality evaluation, even if supposedly simple analyses are being used.

The highly idealized geologic section on the following page shows the relationship of disposal areas 1 and 2 to the ponds, the Cape Fear River and to Orton Pond. Also shown by the arrows are the paths which saltwater intrusion is taking into the various aquifers. The water table in the surficial sands is receiving the largest charge of saltwater. The surficial water table is directly connected to the ponds adjacent to disposal area 2 and to Tom Branch, which flows into Orton Pond. This is the mechanism which has caused the entry of saltwater into the ponds.

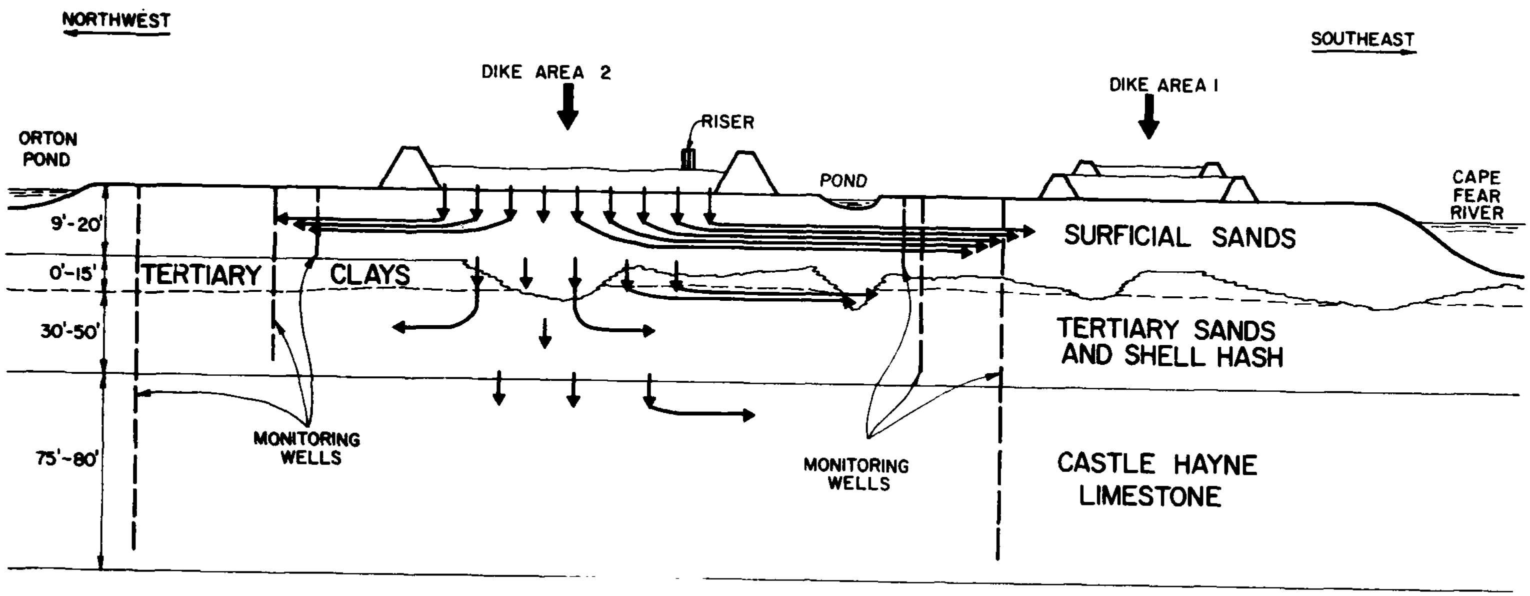
Some of the saltwater in the surficial water moves downward through holes in the tertiary clay. This clay acts as a seal under parts of the area. Once the saltwater moves below the clay, there is no effective barrier to stop the movement of the saltwater into the deeper Castle Hayne aquifer which serves as the water supply for Sunny Point and surrounding communities. By September 1977, saltwater had moved out from and far beyond the boundaries of disposal area 2. Of particular importance is the spread of the saltwater plume into the ponds on the east and north sides of disposal area 2 and the plume which extends down Tom Branch into Orton Pond. Chloride concentrations up to 1,000 ppm have been measured in Orton Pond. Some saltwater damage has occurred to vegetation in Tom Branch of Orton Pond.

On the following page there is a highly idealized geologic profile of the subsurface conditions and the relationship of disposal area 4, which has not yet been used for dredged material disposal, to the Cape Fear River, freshwater ponds and freshwater marshes. Note that a tertiary clay seal is missing below the surficial sands and aquifer. In fact, very little evidence of the clay was found in the area. This indicates a much higher potential for intrusion into deep aquifers than was observed at disposal area 2. There are direct avenues for saline waters from dredged material to intrude into the surficial water table and deeper water tables. Also these ponds and marshes are as susceptible to damage as the ponds bordering disposal area 2.

Chloride concentrations are already elevated at the northwest corner of disposal area 4. The smokehouse well, approximately 500 meters to the north of disposal area 4, pumps from the Castle Hayne aquifer. It was discovered that this well was pumping saltwater in the spring of 1978. High chloride concentrations in the area northwest of disposal area 4 are probably a result of the intrusion of saltwater from dredged material disposed there during the construction of the Military Ocean Terminal in the early 1950's.

The information just discussed comes from a variety of fields - geology, water chemistry, hydrology, and engineering. It is clear that without the combined efforts of these disciplines we would not know very much about the saltwater intrusion problem at Sunny Point. My point is that water quality evaluation is seldom, if ever, a single discipline task.

Lastly, our usual purpose in evaluating water quality is to determine if water is suitable for various uses. Since Sunny Point is entirely Federally owned, used only for military cargo transfer purposes, and potential effects appear to be limited to Federally owned land, except for Orton Pond on the north side of




PURPOSE OF MONITORING WELLS

1. DIRECTION AND RATE OF GROUNDWATER MOVEMENT.
2. MONITOR CHANGES IN THE CONCENTRATION AND AREAL EXTENT OF SALTWATER INTRUSION.

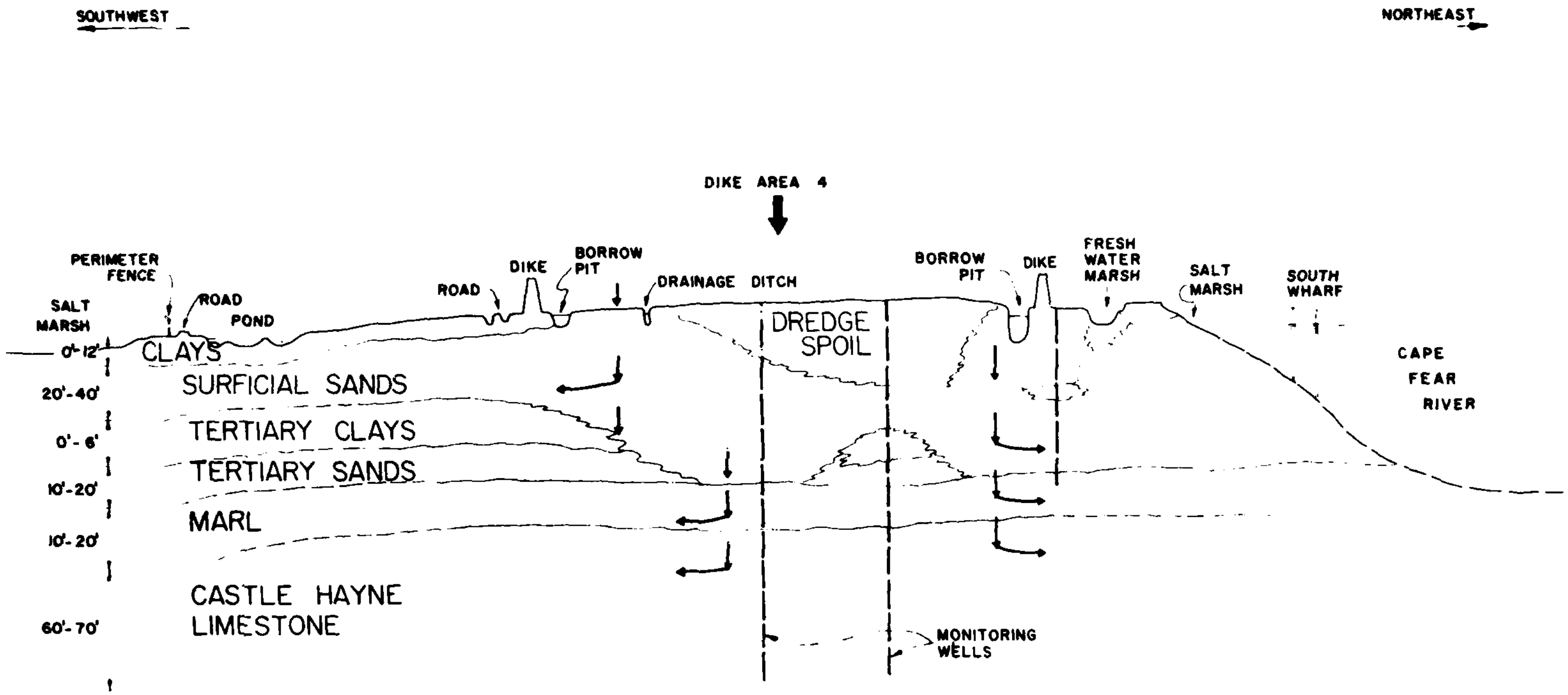
SCHEMATIC
SHOWING MOVEMENT OF SALTWATER IN THE SUBSURFACE
MILITARY OCEAN TERMINAL
SUNNY POINT, NORTH CAROLINA

IMPACT OF SALTWATER INTRUSION

IN SURFICIAL SANDS
1. DESTROYS VEGETATION.
2. DESTROYS AQUATIC LIFE

IN TERTIARY
AVENUE OF DIRECT SALTWATER MOVEMENT INTO CASTLE HAYNE

IN CASTLE HAYNE
POTENTIAL POLLUTION OF "MOTSU" WATER SUPPLY AND THAT OF SURROUNDING COMMUNITIES

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## SCHEMATIC

SHOWING MOVEMENT OF SALTWATER IN THE SUBSURFACE

MILITARY OCEAN TERMINAL
SUNNY POINT, NORTH CAROLINA

IMPACT OF SALTWATER INTRUSION

IN SURFICIAL SANDS
1. DESTROYS VEGETATION
2. DESTROYS AQUATIC LIFE

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IN CASTLE HAYNE
POTENTIAL POLLUTION OF "MOTSU" WATER SUPPLY AND THAT OF SURROUNDING COMMUNITIES.

the installation, you might ask why we are so concerned about saltwater intrusion there. First, the Castle Hayne (deep) aquifer is used for water supply at Sunny Point and nearby communities. As noted before, the movement of saltwater in the Castle Hayne aquifer appears to be slow, but it is clear that movement does occur; therefore, we are concerned about the long term effects of the saltwater intrusion on potential water supply. Second, we are concerned about long term impacts on endangered species. Several areas at Sunny Point, including one area 1,000 feet northwest of disposal area 2, support colonies of red-cockaded woodpeckers which live in old pine trees infected with red-heart disease. Saltwater has killed pine trees in its path, although no red-cockaded woodpecker colony trees have been affected yet. Also alligators nest at Sunny Point. As yet we do not know if saltwater intrusion affects their nesting habitat or not, but we think not. Finally, some of the plants occurring in the ponds have been suggested for threatened or endangered species status.

# A CRITIQUE OF BIOASSAYS USED IN EVALUATING WATER-QUALITY IMPACTS OF CORPS ACTIVITIES

by
Richard K. Peddicord[1]

## INTRODUCTION

This paper outlines some general considerations that must be kept in mind when using bioassays in prediction and evaluation of water quality impacts. Bioassays are useful evaluative tools, but like all tools, they have characteristics that make them useful for particular types of applications. If these constraints are not recognized, bioassays may be designed, conducted, or interpreted inappropriately, resulting in unfounded conclusions. The primary uses of bioassays in the Corps of Engineers at present are for algal evaluations in reservoirs and toxicity tests of dredged material. These topics are discussed in sequence.

In bioassays, organisms are regarded, in a sense, as analytical instruments for determining the environmentally active portions of any contaminants present. Implementation of this approach requires that lack of effect in bioassays be taken to mean that under the experimental conditions contaminants are absent or present only in amount and/or forms that probably are not of major environmental consequence. It is important to realize that a statistical significance in any laboratory bioassay cannot be taken as an absolute prediction that an ecologically important impact will or will not occur in the field. This must be kept in mind when interpreting all bioassay results, particularly in cases where a difference of small magnitude between effects in the control and test conditions is shown to be statistically significant. At present there is no quantitative method for estimating the magnitude of such a difference that might reliably be assumed to predict the occurrence of adverse impacts in the field. Of course, regardless of the magnitude of the difference between mean effects, if the means are not shown to be statistically different, they must be regarded as equal.

## ALGAL ASSAYS

Algae are structurally simplified aquatic plants which can markedly affect water quality through their significant interactions with other components of the aquatic ecosystem. Bioassays have been used in an effort to determine the phytoplankton-limiting nutrient in a water body so that the potential effects of changes in a particular constitutent

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can be evaluated. Both bioassays and chemical measurements have characteristics and limitations which affect their utility in predicting effects of changes in nutrient loadings to water bodies (1,2,3,4,5).

Nutrient bioassays are, in reality, controlled fertilization experiments. Relatively large-scale field fertilization studies have provided useful and reliable information on the eutrophication process. However, algal "bottle bioassays" provide information which must be interpreted with great care when used to predict eutrophication and inappropriate use can produce confusing and ambiguous results (1,4,5). Information on potential growth-limiting nutrients can be obtained from phytoplankton bottle bioassays only during usually very brief and discrete periods of experimentation (1,2,4,5). These data are often incorrectly extrapolated to other seasons (1,5). Various nutrients may influence seasonal phytoplankton growth differently than indicated at the time of the bioassay, possibly leading to substantial errors in interpretation (1,4,5). In nature, mineral recycling occurs among compartments of the whole water body, in contrast to the confined bottle used in bioassays. Test organisms not found naturally in the environment being examined are often used in bottle bioassays, again presenting interpretative difficulties. Different phytoplankton can have different nutrient requirements and exhibit very different growth reponses to the same nutrients under the same conditions (1,2,4,5). Another caution is that bioassays assess effects on a single species in isolation, while in field situations the entire phytoplankton community is affected, with potentially important interactions among species.

Algal bioassays can measure changes in any of several parameters, the most frequently utilized of which are biomass, chlorophyll *a*, respiration and carbon-14 fixation (1,3,4). Each has limitations which affect their usefulness for predicting changes in phytoplankton populations in the field.

The term biomass refers to the mass of living tissue of an organism or a composite of organisms at a given time. It is often difficult to correct biomass estimates for dead mass, and phytoplankton biomass estimates are frequently too large because of the inclusion of suspended detritus. Estimates of algal biomass from chlorophyll or cell volume data are indirect and should be considered only as approximations (1). However, because of the previously noted difficulties associated with the separation of algae from detritus, these approximations of algal biomass are commonly used. Because of its sensitivity and the fact that it estimates carbon fixation by living cells, the carbon-14 technique is most widely used for algal bioassay studies. Techniques for conducting phytoplankton bioassays utilizing the various responses discussed above may be found in several documents (3,6,7,8).

The above considerations must be kept in mind when utilizing either chemical or biological methods for assessing the potential consequences of nutrient changes in water bodies. A combination of chemical and biological evaluations can be utilized on each particular site to take advantage of the characteristics of each approach to best address the

specific questions of interest. In this manner, it is possible to make useful assessments of potential changes in algal populations.

## DREDGED MATERIAL BIOASSAYS

The Environmental Protection Agency/Corps of Engineers' (EPA/CE) Technical Committee on Criteria for Dredged and Fill Material has produced an Implementation Manual for bioassays under Section 103 of the Ocean Dumping Act (9). This manual contains suggested procedures for conducting dredged material bioassays and is widely utilized by coastal Corps Districts and EPA Regions in the ocean disposal regulatory program. The techniques are easily adapted to freshwater applications and are beginning to be utilized in regulatory evaluations under Section 404 of the Clean Water Act.

It should be recognized that dredged material bioassays cannot be considered precise predictors of environmental effects. They must be regarded as quantitative estimators of those effects, making interpretation somewhat subjective. In order to avoid adding more uncertainty to their interpretation, the animal bioassays currently utilized in Corps regulatory programs (9) generally utilize mortality as an end point. The importance of this response to the individuals involved is clear, but the state of ecological understanding is such that it remains impossible to predict the ecological consequences of the death of a given percent of the local population of a particular species. For example, there is presently no basis for estimating whether the loss near a disposal site of 10 percent of a particular crustacean species would have inconsequential or major ecological effects. This interpretative uncertainty becomes overpowering when a parameter whose ecological meaning is not as clear as mortality is used as the bioassay end point. In view of the interpretative difficulties, most regulatory applications do not attempt to consider the ecological meaning of the mortality observed but take the environmentally protective approach that any statistically significant increase in mortality compared to the controls is potentially undesirable. This approach is environmentally conservative in that it does not attempt to consider the ecological meaning of the mortality observed but assumes that any mortality might be adverse.

Most dredged material is generally considered to be relatively unlikely to cause unacceptable adverse impacts in the water column (9,10). This is because relatively few contaminants are released to the water column during a disposal operation, and the maximum possible exposure times for water-column organisms are short and exposure concentrations are low due to dilution and dispersion. If there is to be an environmental impact of dredged material disposal, the greatest potential for impact is widely considered to lie with the deposited sediment. This [illegible] the fact that most contaminants are associated with the sedi- [illegible], and animals, particularly benthic infauna, can be

exposed for extended periods. Therefore, evaluation emphasis should generally be placed on the deposited sediment.

Phytoplankton bioassays can indicate the potential for stimulation or inhibition by the dredged material in question. However, it is widely felt that potential effects on phytoplankton are generally of little environmental concern at dredged material disposal sites, due to the extremely dynamic and variable characteristics of natural phytoplankton assemblages and to the rapid mixing and dilution that occur in the water column (11). In addition, phytoplankton bioassays using the suspended particulate phase (i.e., a phytoplankton "turbidity bioassay") are extremely difficult to conduct and interpret because of interferences and predation on the test species by indigenous protozoans in the dredged material being tested. The presence of suspended particulates significantly interferes with the determination of response in many cases, leading to a recommendation against attempts to use suspended particulate phase phytoplankton bioassays (3,9). For these reasons, unless there is a specific reason to be concerned about potential effects of the proposed operation on phytoplankton, phytoplankton bioassays of dredged material are generally not conducted.

The collection and preparation of dredged material samples for testing are one of the more important phases of evaluating the impact of dredged material discharge upon the aquatic environment. Samples that are improperly collected, preserved, or prepared will totally invalidate any testing conducted and will lead to erroneous conclusions regarding the potential impact of the proposed discharge. Meticulous attention must therefore be given to all phases of water and sediment sampling, storage, and preparation. The number of sediment samples to be taken from the dredging site for processing must be carefully considered because of the extremely heterogeneous nature of samples of this type. The largest source of variation between dredged material samples taken at a dredged site is often the vertical and horizontal distribution of the samples (11). The sampling stations should be located throughout the area to be dredged and should be selected to characterize obviously contaminated as well as noncontaminated areas.

The usefulness of all bioassays is dependent to a large extent on the selection of appropriate species. One of the major requirements for reliably obtaining consistent and reproducible data is that the species be known to be routinely adaptable to laboratory conditions. At the same time they must be sufficiently sensitive to the contaminants likely to be in the dredged material to show effects if those contaminants are present in biologically active forms. Since it is not presently possible to make direct extrapolation from laboratory bioassays to quantitatively predict field impacts, it is not necessary to use organisms collected near the disposal site. However, test species should be related phylogenetically and/or by ecological requirements or functions to the species of major concern in the area of the proposed disposal operation. Commercially important organisms in the vicinity of the disposal site are often included.

It is recommended that juvenile forms be utilized because of their generally greater sensitivity than adults. Molluscs generally are relatively resistant to many toxicants and therefore are often undesirable for bioassays, but they are very useful for bioaccumulation studies. To avoid predation, it is often necessary to conduct the bioassay with potential predator and prey species isolated from each other. For example, fish and zooplankton or larvae must be separated to avoid predation. The identity of all test species must be verified by experienced taxonomists.

Bioassays of the standard elutriate, sometimes called the liquid phase, can aid in evaluating the importance of dissolved chemical constituents released from the sediment during disposal operations. The procedure is very similar to techniques long used for acute toxicity bioassays of solutions with only slight modification (3,9). This procedure can also be used to evaluate the effect of suspended particulate matter that is present in the water column for certain periods of time during disposal of dredged material. A series of experimental treatments and controls is established using the liquid phase or suspended particulate phase of the dredged material. The test organisms are added to the test chambers and incubated under standard conditions for a prescribed period of time. The surviving organisms are examined at appropriate intervals to determine if the test material is producing an effect.

Biological response to all toxicants is a function of both the concentration of contaminants and the length of time animals are exposed to that concentration. In the regulatory application of bioassay data, the importance of the time-concentration relationship is often improperly overlooked or minimized. In an actual field disposal, operation chemical concentration is constantly and usually fairly rapidly decreasing due to mixing and dilution. Thus, the magnitude of the concentration to which animals are exposed is constantly decreasing, and the total time of exposure before concentrations are reduced to background is fairly short, usually on the order of a few hours (12). This is far different from standard test conditions where animals are exposed to constant concentrations for a fixed 96-hr period. Therefore, in applying bioassay results it is necessary to consider mixing and dilution and determine whether animals in the field are likely to experience concentrations and exposure times approaching those shown to have an effect in the laboratory (9).

A benthic bioassay can aid in assessing the potential environmental impact of the solid phase of dredged material and acts as an indirect indicator of chemical toxicity of the sediment. It provides exposure conditions approximating those that would be experienced by animals living near the boundaries of the disposal site. Several benthic species are allowed to establish themselves in an appropriate reference sediment and are then covered with a layer of the dredged material being evaluated. Survival in the dredged material relative to that in the reference sediment is used as the primary biotic response criterion.

No objective method of considering mixing and dispersion of the sediment after it reaches the bottom has been devised for use in applying solid phase bioassay data to field conditions. Rather, there has been an attempt to incorporate the phenomenon of solid phase sediment dispersion into the solid phase bioassay design currently recommended by the Corps. Since the concept of a disposal site implies that conditions within that site may be adverse, but that conditions beyond its boundaries cannot be, the solid phase bioassay technique does not evaluate the physical effects of massive sediment deposition immediately under the discharging vessel. Instead, the technique generally approximates conditions near the disposal site boundary where sediment dispersion has reduced the depth of deposited dredged material to a few centimetres. The solid phase bioassay technique measures the effects of chemicals associated with this deposited sediment, rather than physical effects of the sediment. It is apparent that there will be a gradient of decreasing effects with increasing distance away from the disposal site due to dispersion, although the nature of this gradient cannot be determined.

Sediment bioassays cannot be used to determine the cause of the observed effects. Indeed, if an adverse effect may occur outside the disposal site, it matters little from a regulatory viewpoint which chemical constituent(s) associated with the sediment carried beyond the site causes that effect. Therefore, it is important to realize that a benthic bioassay measures the total chemical impact of the dredged material. That impact may be due to an unrecognized pollutant or to the synergistic effects of many pollutants, none of which may have an exceptionally elevated concentration. At the present technical state of the art, it is not possible to determine by any known chemical analysis which pollutant(s) may be the causative agent(s).

## SUMMARY

If constraints such as the above are kept in mind, it is possible to use bioassays as important tools in many water quality evaluations. They provide information on biological availability and activity of contaminants not obtainable in any other manner. Yet it must be kept in mind that the application of results of any laboratory experiment, be it chemical or biological, cannot be quantitatively extrapolated to the field. Application of laboratory results to field situations requires judgment and estimation of how a host of environmental variables will affect the phenomenon under consideration.

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USE OF MONTE CARLO SIMULATIONS TO EVALUATE RESERVOIR OPERATIONS

by

Joseph L. Norton[1]

Reservoir operation and management and the subsequent impact on water quality are of considerable concern to most of us in attendance at this meeting. This topic is one of the underlying considerations of the Environmental and Water Quality Operational Studies (EWQOS). This paper will present some information on the use of Monte Carlo techniques and the value of these techniques in the evaluation of reservoir operational and management alternatives.

Before I discuss Monte Carlo simulations, however, it is instructive to review some of the background, assumptions, and limitations of modeling in general, and water quality models in particular.

What is a model? A model is an abstraction of a system that can be verbal, graphical, physical, or mathematical. This is the first of many definitions I will present. We develop mathematical models for several reasons: (1) to organize our thoughts concerning the system; (2) to use as a research tool in simulations; (3) to identify gaps in our knowledge of the system; (4) to aid the decision maker in choosing among alternatives; (5) and lastly, as a teaching device.

Mathematical models have certainly come of age because they force the investigator to formulate ideas precisely and concisely; the system is in a precise language which encourages the manipulation of ideas; after all, mathematics is really just a language like French or English with a precise shorthand notation. A large number of theorems are available to describe various phenoma. Modeling is facilitated by the ubiquity of high-speed computers.

A model is an abstraction of reality that describes, in either qualitative or quantitative terms, a certain set of complex interrelationships of the system being studied (Snodgrass, 1979). A mathematical model is an abstract simplified mathematical construct representing a part of reality and created for a particular purpose. In our case the purpose or objective is to develop a generalized reservoir water quality model (or models) useful for planning and managing reservoirs.

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Next, I should reiterate the simplifying assumptions and limitations of the model as of 1 January 1980. It is a one-dimensional model maintaining only the vertical dimension. The reservoir is conceptualized as a stack of uniformly mixed layers. The results generated are generally considered as representative of the deepest portion of the reservoir. Simplified ecology is necessary because it would be impossible to describe adequately all of the interactions in so complex a system. All simulations are considered to be in the aerobic environment. While there are certain defaults in the model, simulations in anaerobic and postanaerobic situations are probably not valid. The density of water used for calculation in the model is a function of temperature only. Therefore, situations involving high dissolved or suspended solids would not be simulated properly. The dynamics of each chemical and biological component is described by the principles of conservation of mass and the kinetic principle. The kinetic principle states that internal changes such as respiration, decay, etc., occur through rate kinetics. Conservation of mass then becomes a matter of bookkeeping. The model considers all nutrients to be completely available for uptake. This may not be a serious limitation when light or some other physical factor limits growth. The simulation is assumed to take place in an ice-free environment, thus limiting the simulation period to those times of the year between spring thaw and the fall turnover and cooling period. Lastly, there is no algorithm for toxic materials currently included in the model. Before leaving the discussion of limitations, I must point out that many of these problem areas are being addressed in EWQOS, and new algorithms will be available soon.

Some typical water quality problems that the model is designed to address involve low dissolved oxygen resulting from a number of sources; high nutrient loadings from both point and nonpoint sources; high coliform counts in terms of die off; nuisance algal blooms, which could affect both water supply and recreation; and water quality standards, both in the pool and in releases.

Reservoir management techniques which might be investigated include selective withdrawal operation, changes in pool elevation, altered release rates, and destratification efforts. The real economy of modeling

is seen here in the evaluation of these structural or operational changes without committment of significant resources. This can be extremely important in preimpoundment studies. Management is often directed toward meeting water quality standards and criteria both downstream from the impoundment and within the pool. The outcome of the Richard B. Russell and Hartwell questions is definitely impacted here. In fact, most of the usual project purposes are either impacted by or impact upon project water quality (recreation, water supply, irrigation, flood control, navigation, and hydropower).

With objectives, limitations, and uses as a background, now consider the current model status and operation. There are three general types of data required to run the model: (1) coefficients, which describe the rate kinetics I mentioned earlier, (2) initial conditions of each parameter, and (3) parameter update information which provides new values for parameters at specific intervals.

Biological parameters consist of two assemblages of algae, a zooplankton, three fish, coliform bacteria, benthos (represented as a single compartment), and detritus. Chemically, we are concerned with alkalinity, pH, dissolved organic material, dissolved oxygen, total dissolved solids, three forms of nitrogen (nitrate, nitrite, and ammonia), phosphorus, and organic material in the sediment. Two physical components are considered; temperature and hydrologic inputs. With a given set of initial conditions and periodic update information concerning these parameters, a single time history for each component in each layer will be generated (Figure 1). Note in Figure 1 that each compartment has a separate trace from Julian Day 95 to 330. Each time the model is executed with this data, the same time history for this layer will be predicted for the algae 1 assemblage and the algae 2 assemblage. This is known as a deterministic simulation. Another example of a deterministic simulation is found in Figure 2, where the influence of two different release rates on biomass of algae 1 is considered. Note the apparent bloom spikes predicted for Julian Day, about 140 and 160. Figure 3 shows a comparison of selective and surface withdrawal operation on concentration of algal assemblage 2. Here the bloom beginning about Julian Day 200 under surface withdrawal,

is absent under a selective withdrawal scheme. The last deterministic simulation I will present is given in Figure 4 which compares algal assemblage 2 response to alteration in pool elevation of 1.5 m. Blooms are predicted to be about 30 days later at the lower elevation. The important concept of these deterministic simulations lies in the fact that for a single set of coefficients, initial conditions and updates, the same time history will always be generated. A single time history results in spite of the fact that there are large differences in literature values for most coefficients depending many times on the investigator, experimental conditions, experimental techniques, etc. One time history results because once the coefficients for the model have been assigned, and the data read, there is no uncertainty about the results. Uncertainty pervades the real world and, therefore, must necessarily be a part of our prediction. To achieve uncertainty then, it is necessary to have some element of probability as base for the simulation. Monte Carlo simulation is one method of accomplishing this result.

Monte Carlo techniques are included in the model as a separate subroutine that is called when the modeler desires stochasticity in the predictions. It can be seen from this flow chart (Figure 5), that without invoking the Monte Carlo routine, the deterministic simulation is achieved. Upon command, however, the coefficients and updates are generated on a daily basis. The simulation proceeds thusly throughout the year. At the end of the simulation year, the program loops back and begins again with the same initial condition. This iterative process can be repeated as many times as desired. Figure 6 shows the family of time histories generated in a Monte Carlo run. Remember that there is one of these figures for every parameter in each layer. Note the similarities of each trajectory or time history with respect to major features of the simulation. We are able to generate values for a number of parameters and coefficients in the simulation. Table 1 shows a type of distribution for several coefficients which are varied through Monte Carlo routine. Three distributions are indicated here; normal, rotated log normal, and uniform. Actually, four distributions, as indicated in Figure 7 can be used, depending on the nature of the data.

Figure 8 is a plot of percent of occurrence versus algal assemblage 2 growth rate, an example of a normal distribution. This broad distribution results in many instances from differences in literature values or from grouping of various types of algae (e.g., green algae and diatoms) to form the assemblage. Figure 9 is typical of half-saturation concentration plots, which are fitted to a rotated log normal distribution. Figure 10 shows a plot of inflowing phosphorus values which follows a typically log normal distribution. It is important to point out that any distribution could be specified, depending on the nature of the frequency histogram generated in compiling available data. The four distributions shown here represent most of the cases which we have encountered.

It is possible now to compare the values generated by stochastic simulation for alternate reservoir management techniques. In Figure 11, the 95 percent confidence interval of the values have been shaded differently to illustrate the range generated from simulation with surface versus selective withdrawal schemes. Note that under the Monte Carlo process, little difference is seen except for minor variation in timing and magnitude. In Figure 12, where the same statistics have been plotted the selective withdrawal produces results which are significantly lower than the bottom withdrawal scheme. In Figure 13, where destratification was investigated versus a base case simulation, higher algal blooms will be predicted as a result of destratification. Note, however, the overlap of possible values. An earlier figure depicted the deterministic simulation of pool elevation and significant changes in timing and magnitude of algal blooms resulted. Results may not be so clear cut when the simulation is made using the Monte Carlo procedure (Figure 13).

The reasons for using Monte Carlo should now become evident. First, to compensate in some degree, for the simplification of ecology; secondly, to account for some of the intrinsic variability of organisms; next, to help overcome the confining one-dimensional assumption; fourth, to overcome for the lack of specific data items; and lastly, to offer some estimate of the statistical reliability of the prediction. The probablistic nature imparted by Monte Carlo procedure produces information which could not be gained from deterministic simulation.

A good indication of this is presented in Figure 14, where the mean value of the Monte Carlo runs is contrasted to a deterministic solution run with mean coefficients and parameters. As in Figure 15, obvious differences appear. Again, in Figure 16, significant differences are seen in both timing and magnitude of algal blooms. I think this points up some of the possible problems of performing ecological modeling using "average" literature values for the coefficients and some benefits of Monte Carlo simulation.

Consider again a series of Monte Carlo runs (Figure 17). It is obvious that if the system were fairly stable, then the closer together the predictions are at some day in the simulation, the more confidence the modeler can place in the results. If the average and standard deviation parameters were calculated on the specific day after a family of ten curves had been generated and the standard error calculated as the standard deviation divided by the square root of number of iterations, then we can plot the mean and indication of the amount of scatter about that mean (Figure 18). A good Monte Carlo simulation would yield a stable mean and standard error. In Figure 18, the mean increases to a fairly stable level and the standard error levels off after 40-50 iterations for both simulations. This phenomenon is called convergence. Convergence is a necessary part of Monte Carlo simulation because it reflects the confidence the modeler has in prediction. In most cases, the magic number of 40 iterations has produced convergence.

I would like to state that the expense of Monte Carlo simulation is but a small portion of this type of study. The bulk of expense would be associated with data collection and interpretation of results. Considering the necessity of confidence in this forecasting technique, and the value of the information received, Monte Carlo simulation modeling can be an extremely important tool for the Corps of Engineers.

In summary, we have discussed ecological modeling and the role of Monte Carlo procedures in introducing a necessary element of uncertainty. Yet another definition of the model is "something that mimics the relevant features of the situation being studied." I'm absolutely certain that uncertainty is a relevant feature of reservoir operation and management.

Therefore, we conclude that Monte Carlo simulations can provide the decision maker with much needed statistical information to realistically evaluate reservoir management and operation techniques. That's what predictive techniques are all about.

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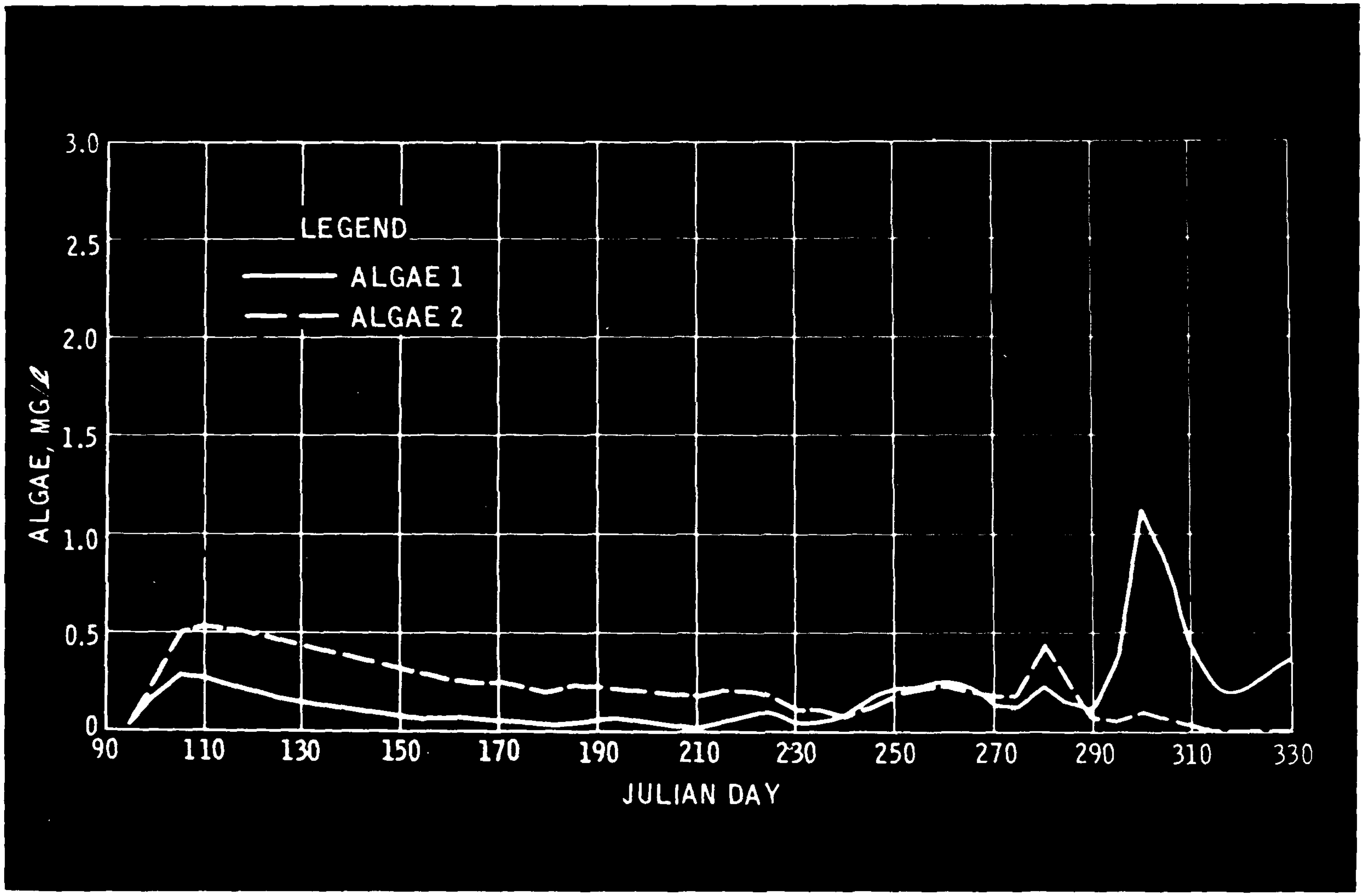



Figure 1. Time histories of the algal compartments generated by deterministic model simulations

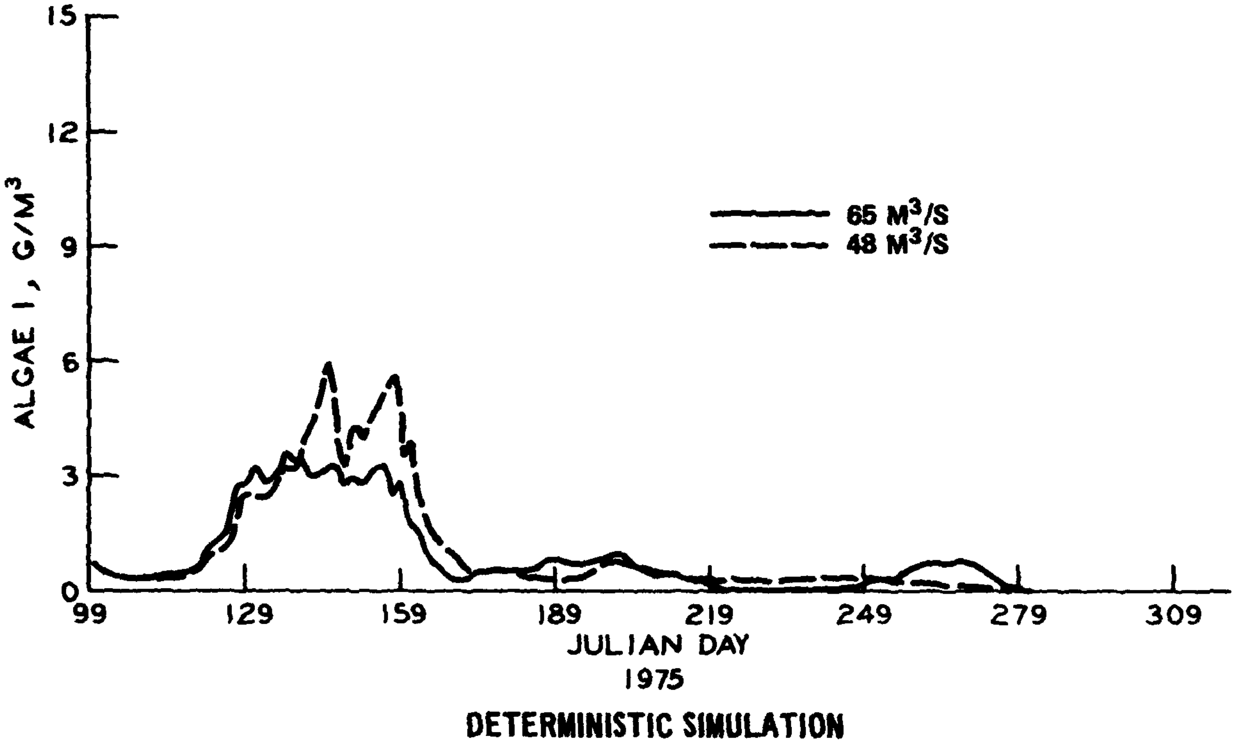



**Figure 2. Deterministic simulations of biomass of algae assemblage 1 at two release rates**

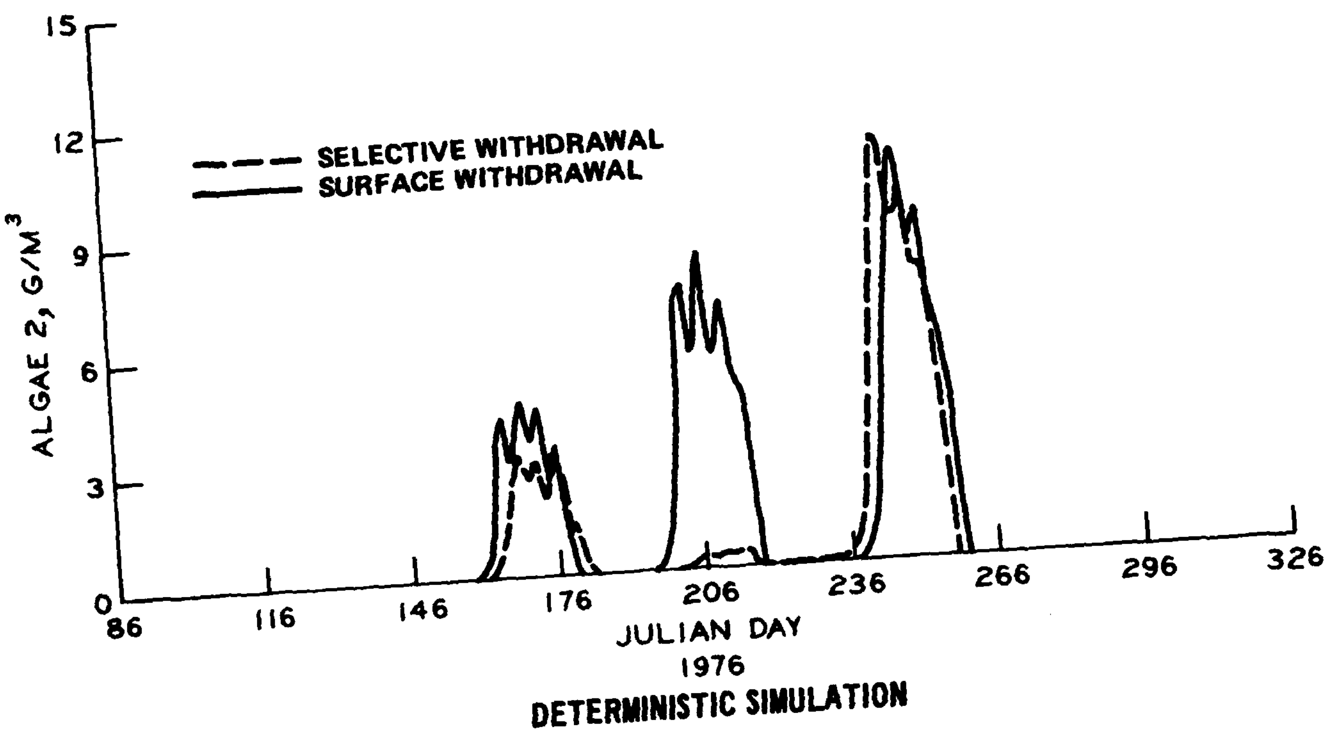



Figure 3. Deterministic simulation of algae 2 biomass under selective and surface withdrawal schemes

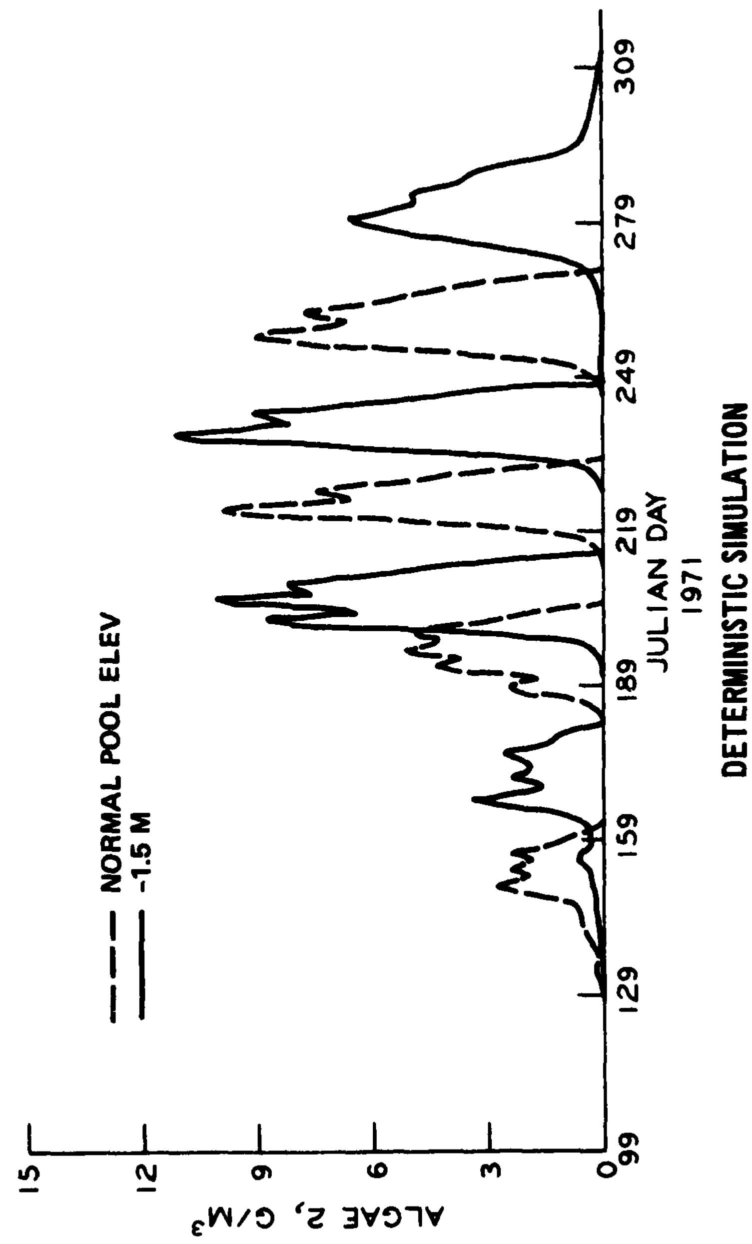
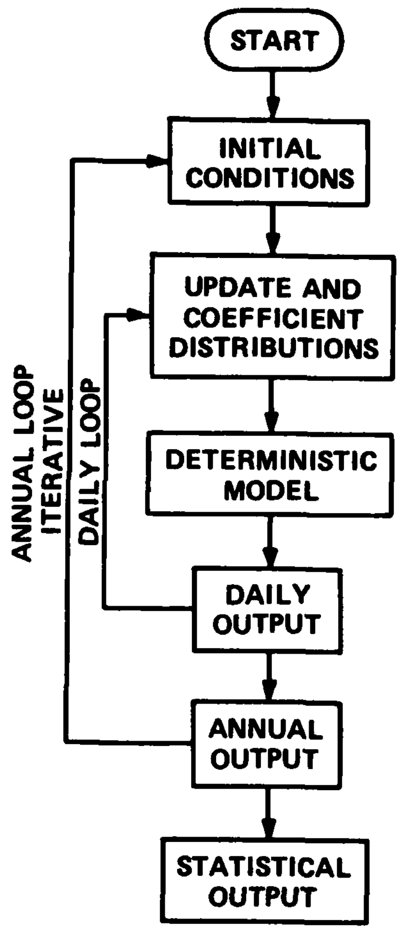



Figure 4. Deterministic simulations of algae 2 biomass comparing normal pool elevation with a lower pool elevation




MONTE CARLO FLOW CHART

Figure 5. Monte Carlo flow chart

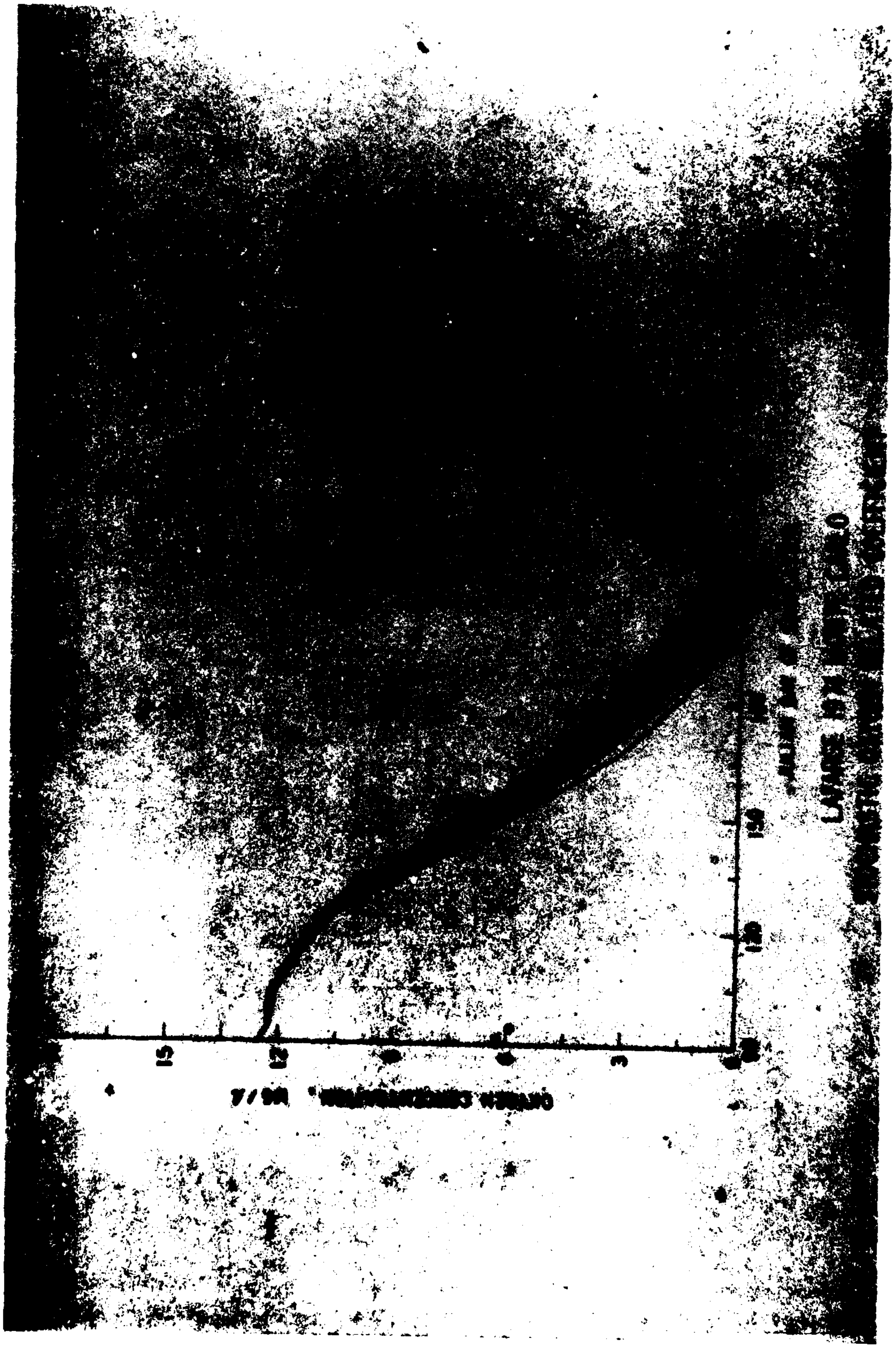


Figure 6. A family of time histories generated in a Monte Carlo run
(Thornton, et al. 1976)

## RANDOMIZED COEFFICIENTS

| VARIABLE | DISTRIBUTION | | |
|---|---|---|---|
| | NORMAL | ROTATED LOG NORMAL | UNIFORM |
| GROWTH | ALGAE<br>ZOOPL. | | |
| RESP. | ALGAE<br>ZOOPL. | | |
| MORTALITY | ZOOPL. | | |
| HSC | | P, N | |
| SETTL. | | | ALGAE, DETRITUS |
| DECAY | | | $NH_3$<br>$NO_2$<br>DETRITUS<br>DIS. ORG.<br>COLIF. |

Table 1. Coefficients Which May be Varied Through Monte Carlo

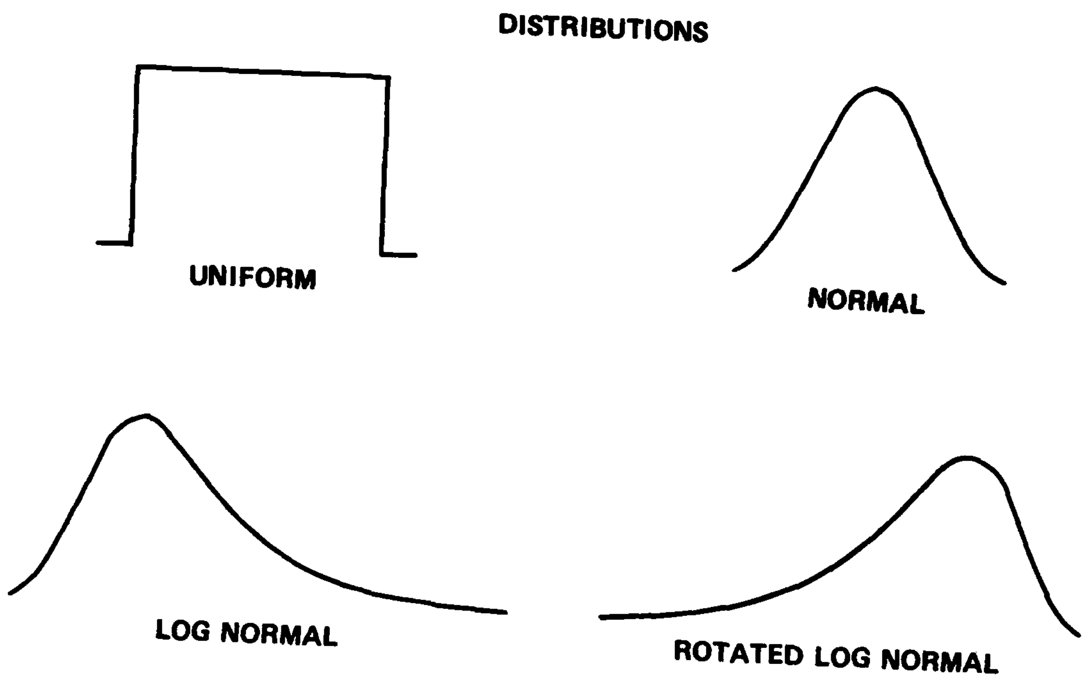



Figure 7. Four distributions utilized in the Monte Carlo routine to fit data for the randomization process

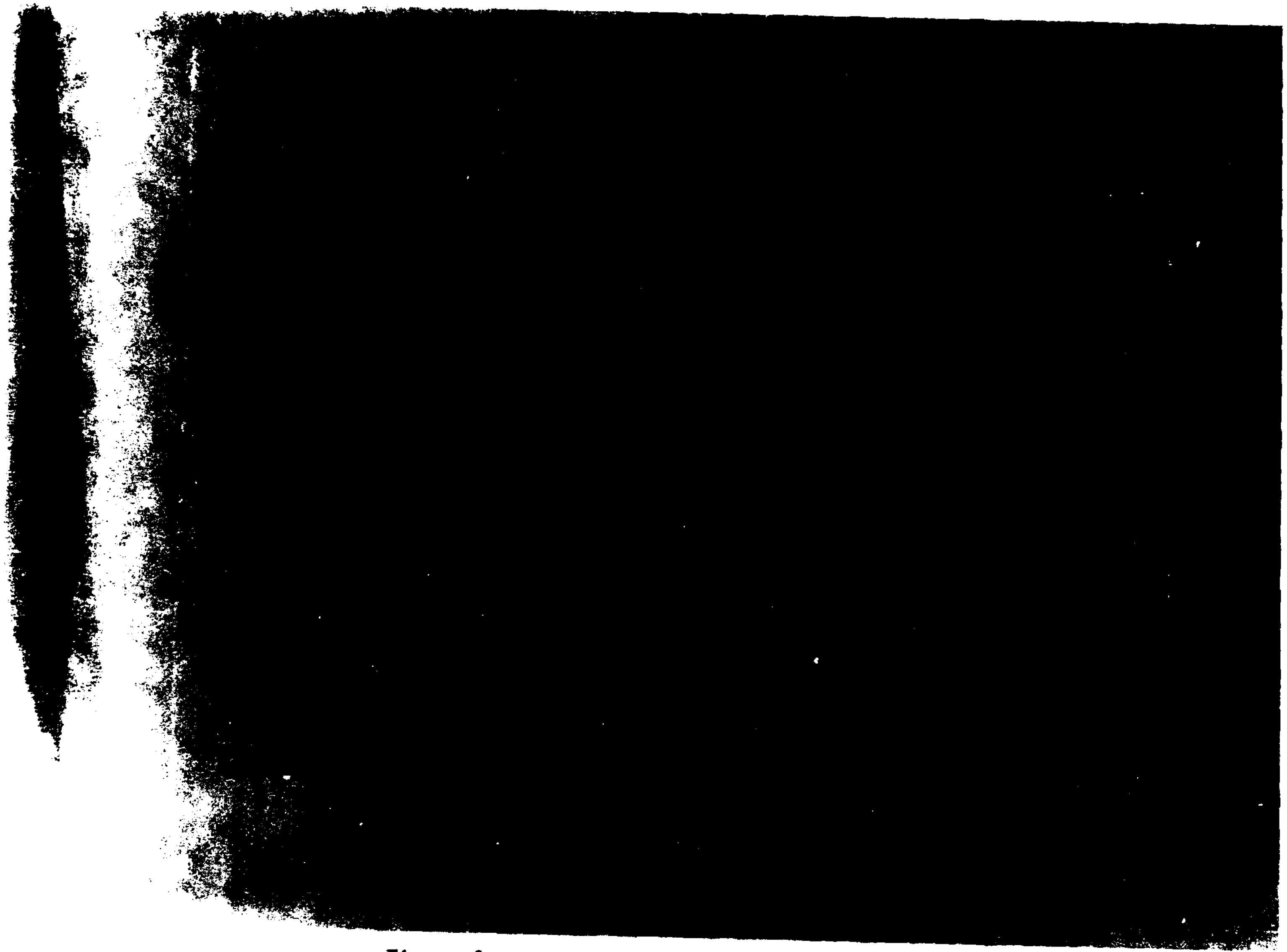


Figure 8. Values for growth rate of algal assemblage 2 are plotted against frequency of occurrence and are distributed normally

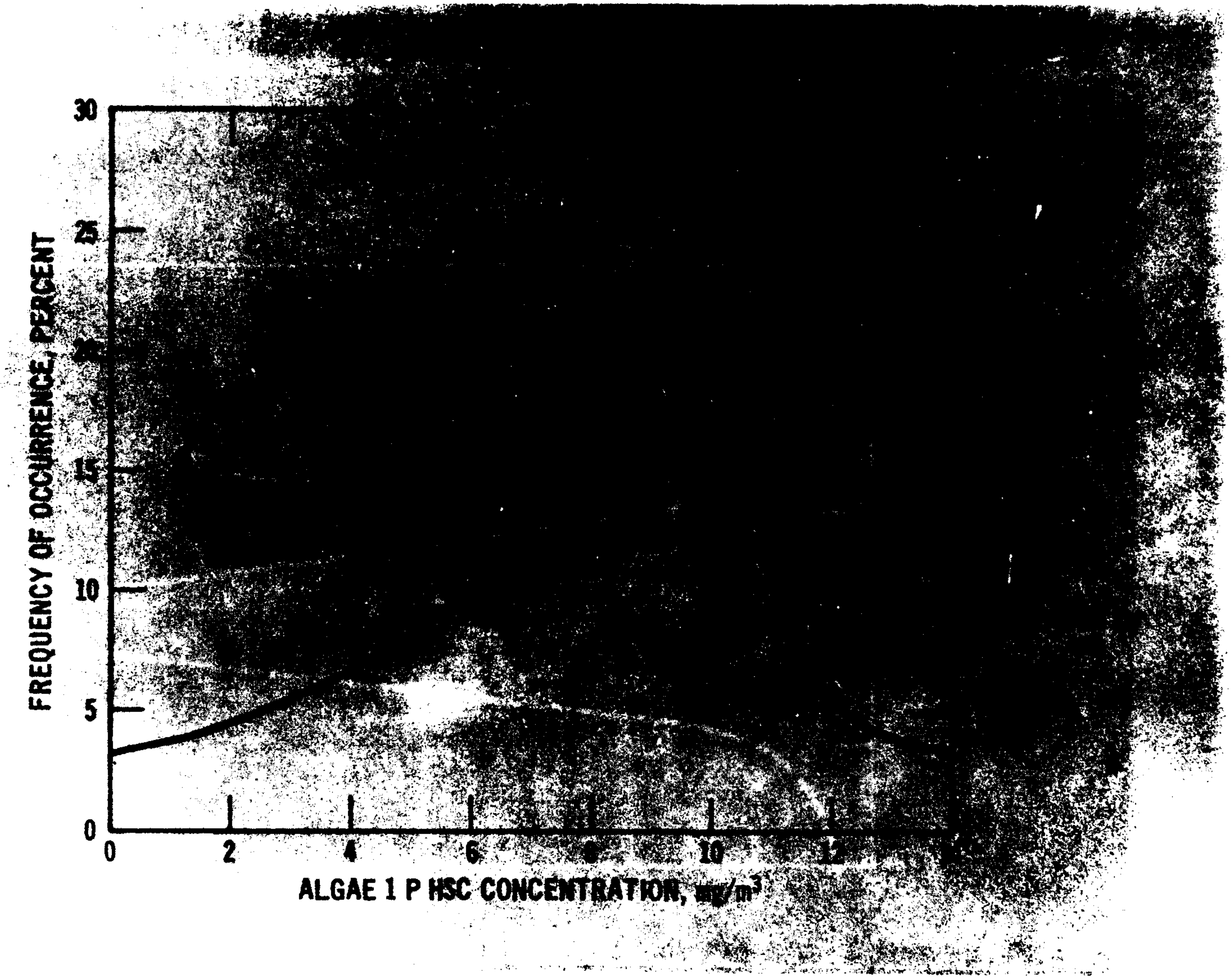



Figure 9. Half saturation values for phosphorus are plotted against frequency of occurrence and distributed as rotated log normal

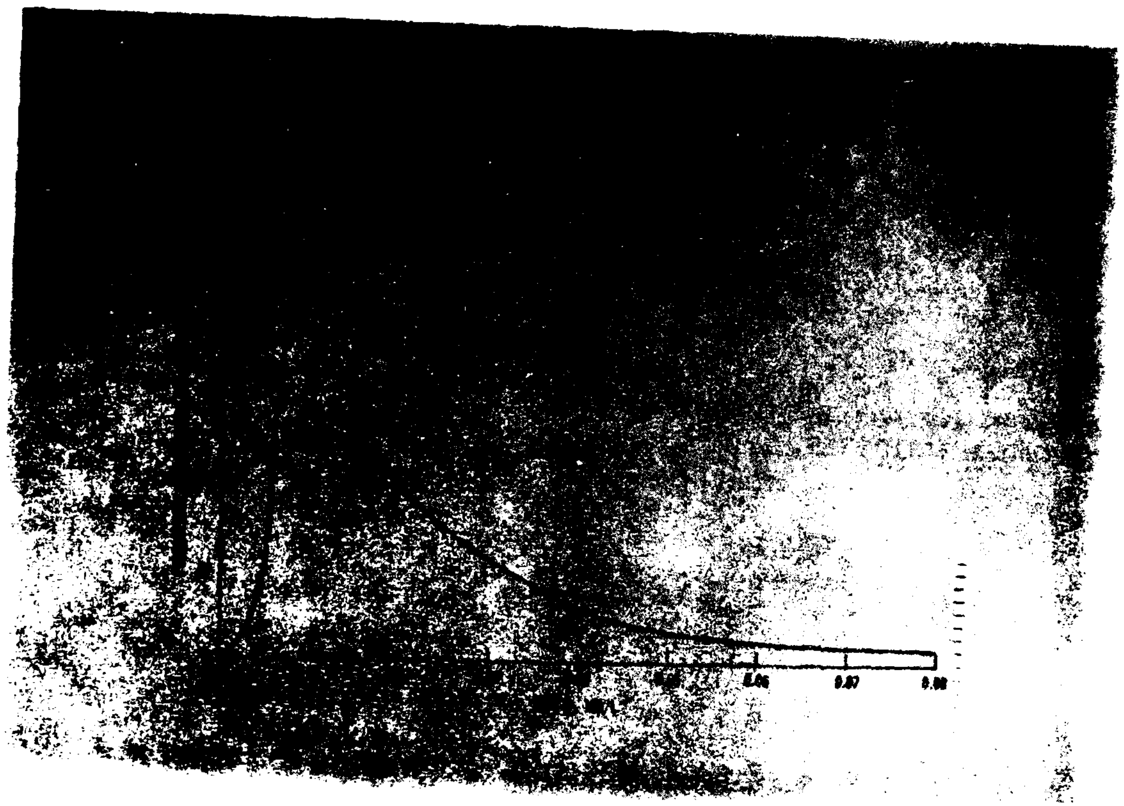


Figure 10. The frequency of occurrence of inflowing phosphorus values are distributed log normally

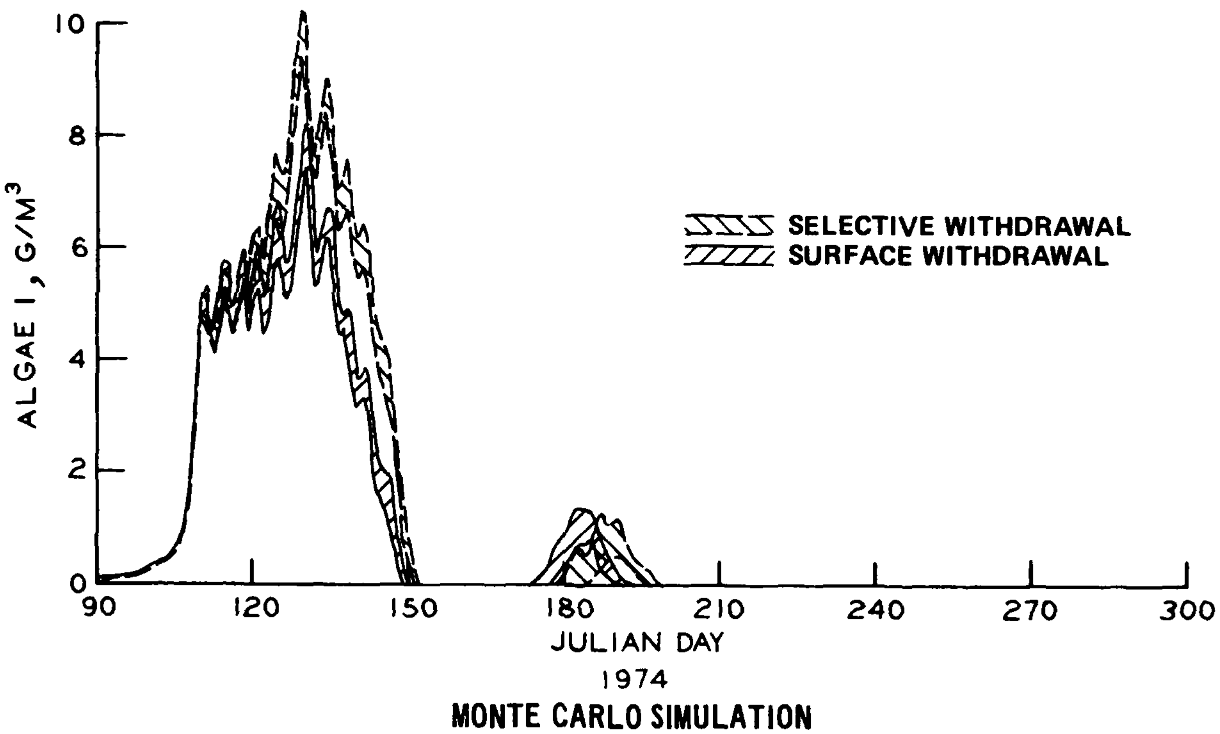



Figure 11. Ninety-five percent confidence intervals for algae 1 biomass predictions using Monte Carlo techniques to compare selective versus surface withdrawal

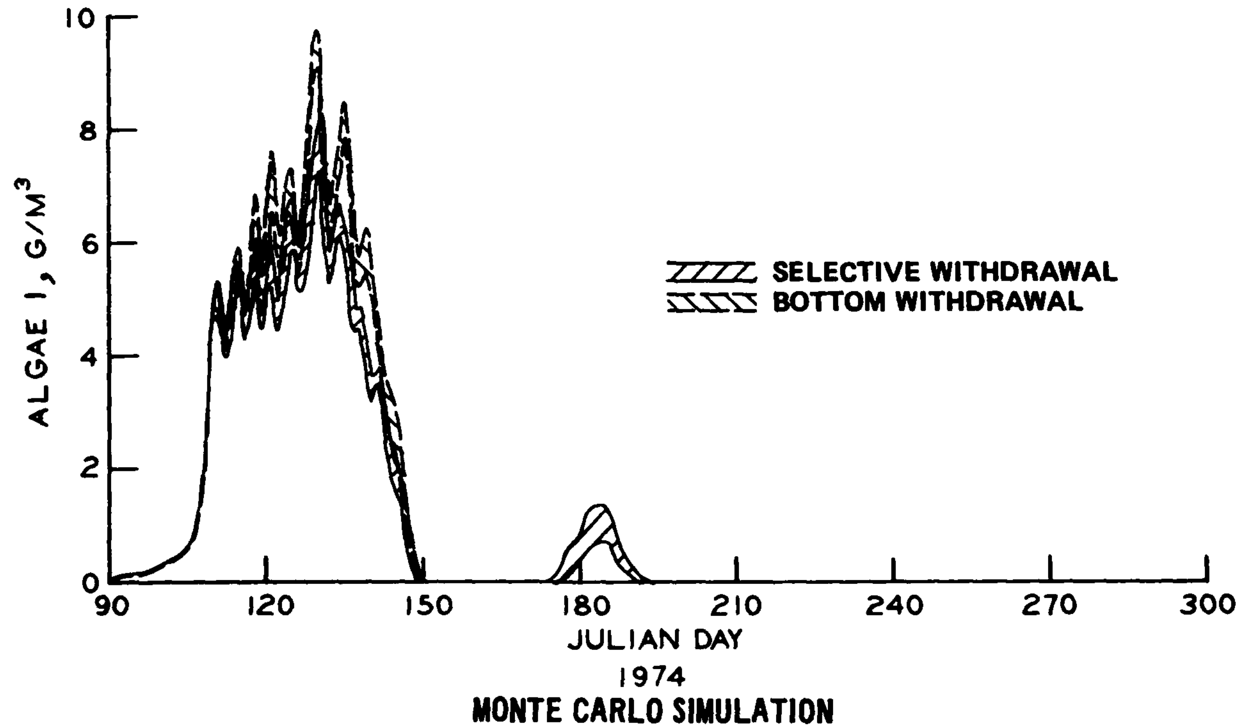



Figure 12. Ninety-five percent confidence intervals for algae 2 biomass predictions using Monte Carlo techniques to compare selective versus bottom withdrawal

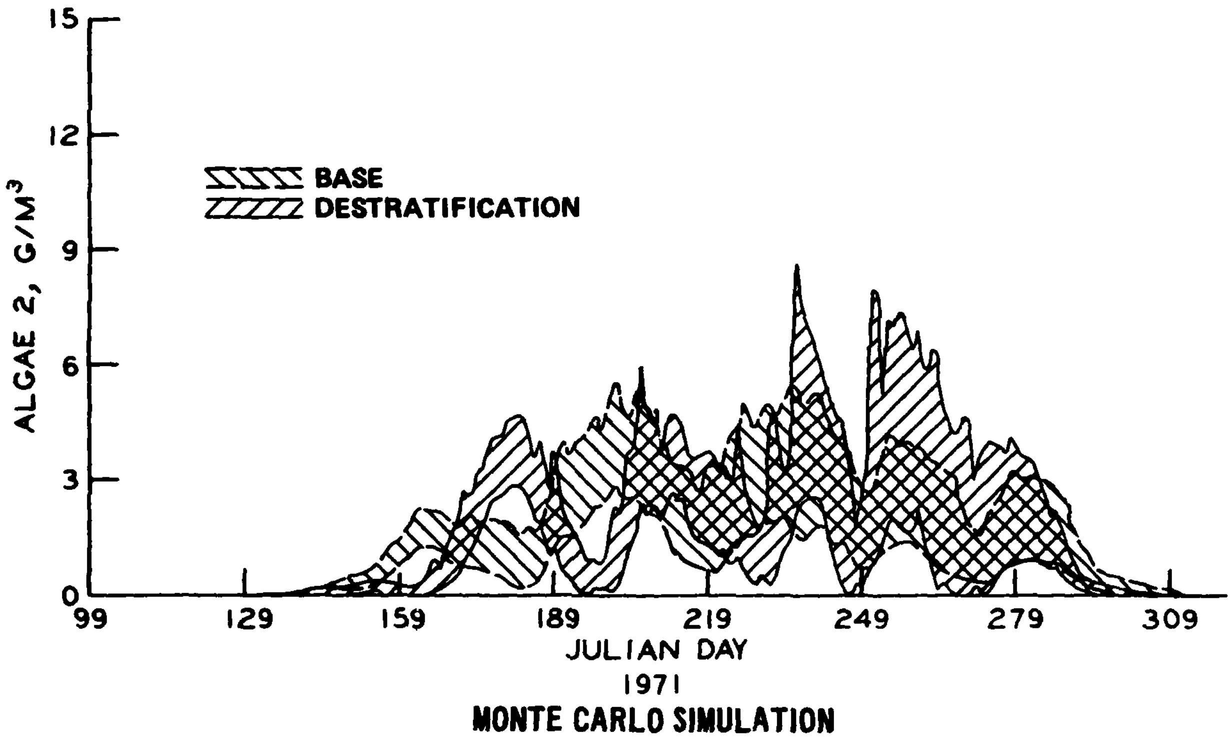



Figure 13. Ninety-five percent confidence intervals for algae 2 biomass predictions using *Monte Carlo* techniques to *compare base case* simulation with simulations of destratification

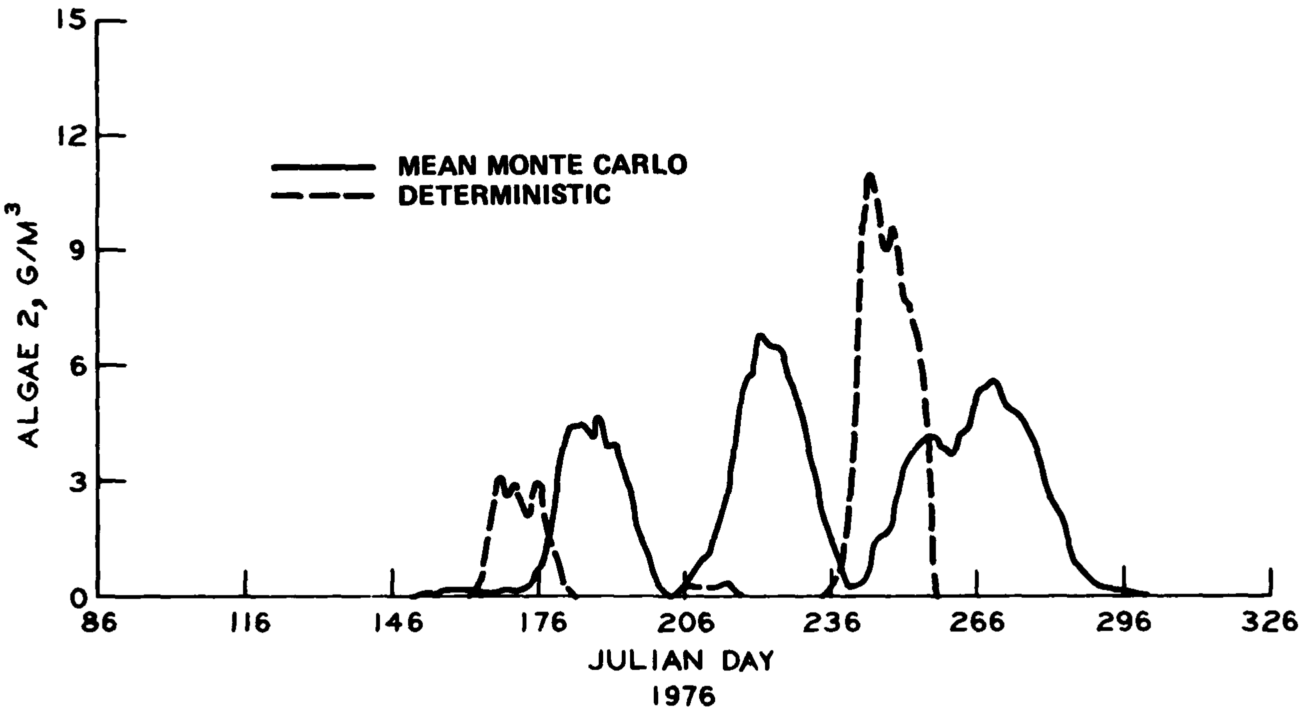



Figure 14. Algae 2 biomass predicted by use of mean coefficients in a deterministic mode compared to the mean of several Monte Carlo predictions

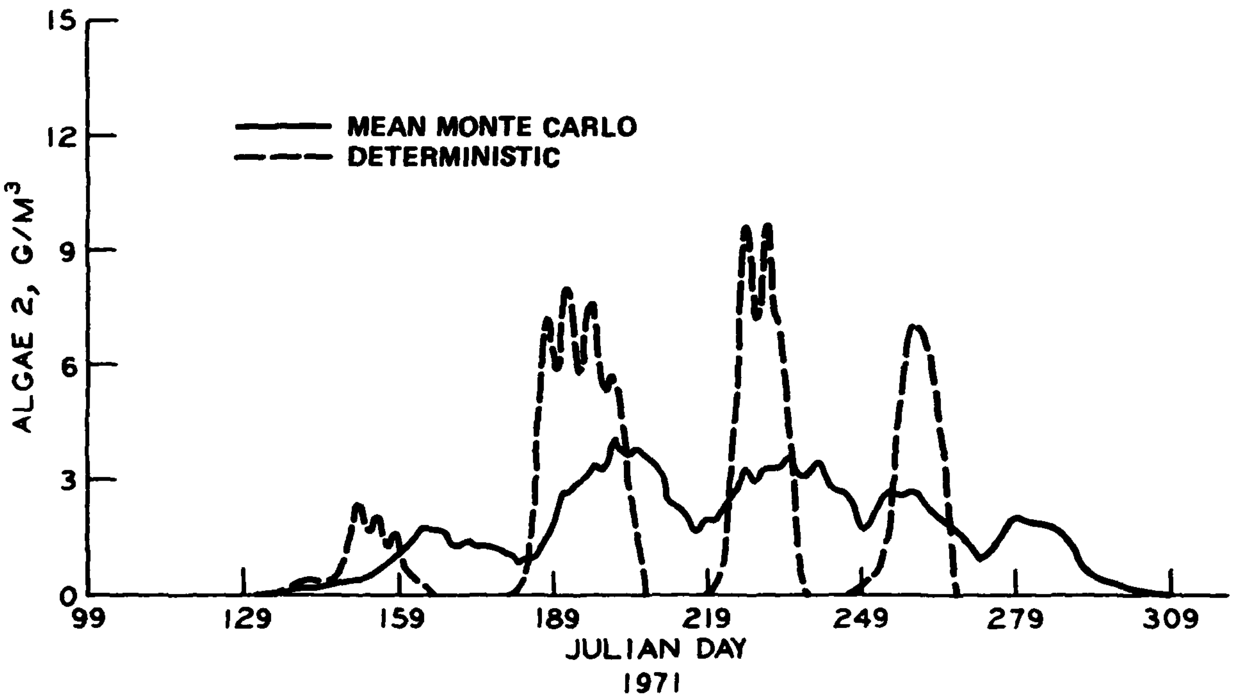



Figure 15. Algae 2 biomass predicted by use of mean coefficients in a deterministic mode compared to the mean of several Monte Carlo predictions

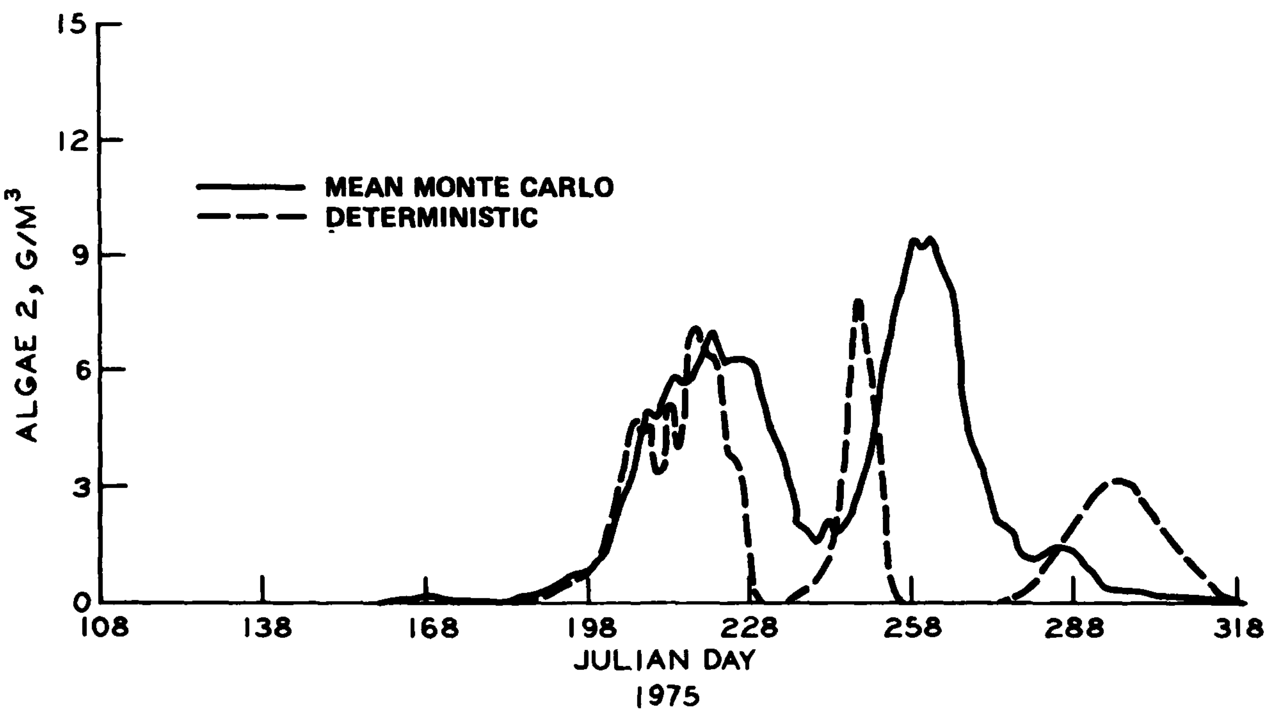



Figure 16. Algae 2 biomass predicted by use of mean coefficients in a deterministic mode compared to the mean of several Monte Carlo predictions

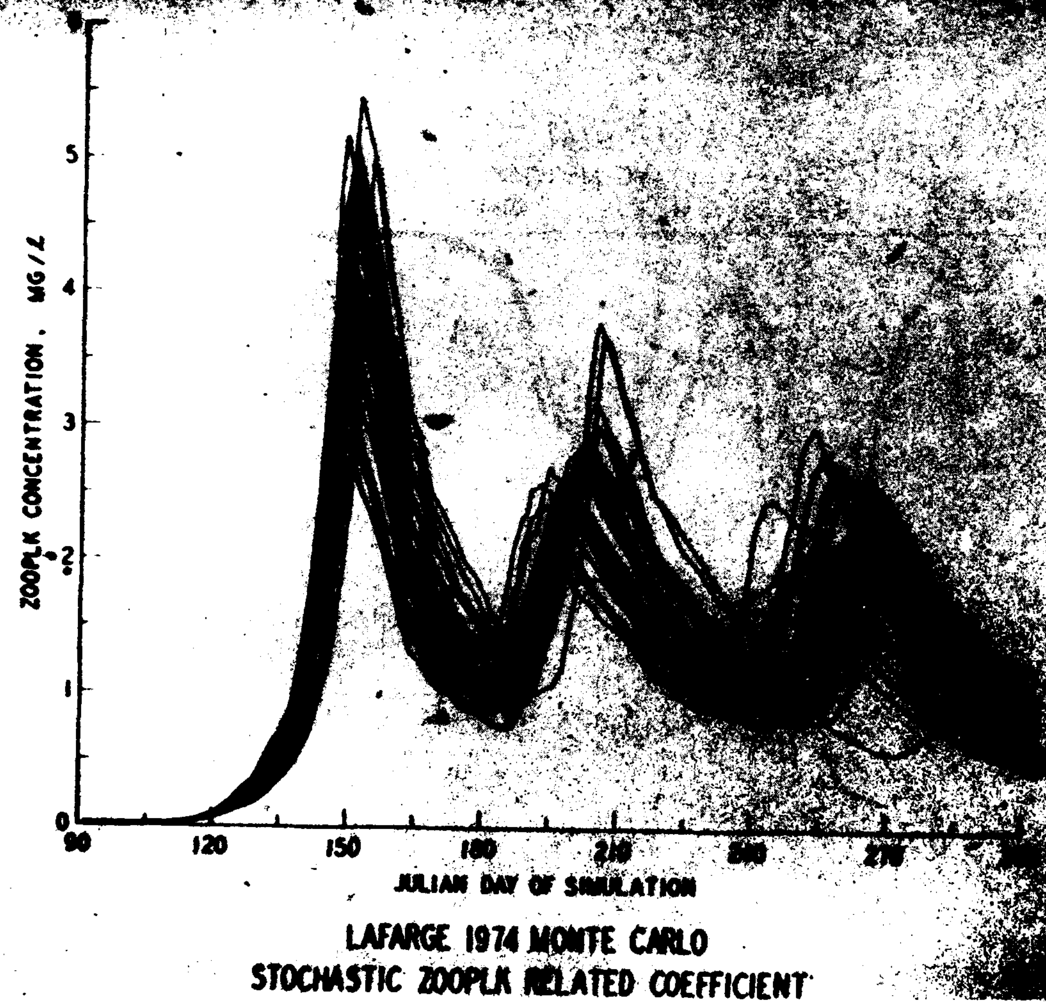



Figure 17. Zooplankton biomass predicted by Monte Carlo simulation technique

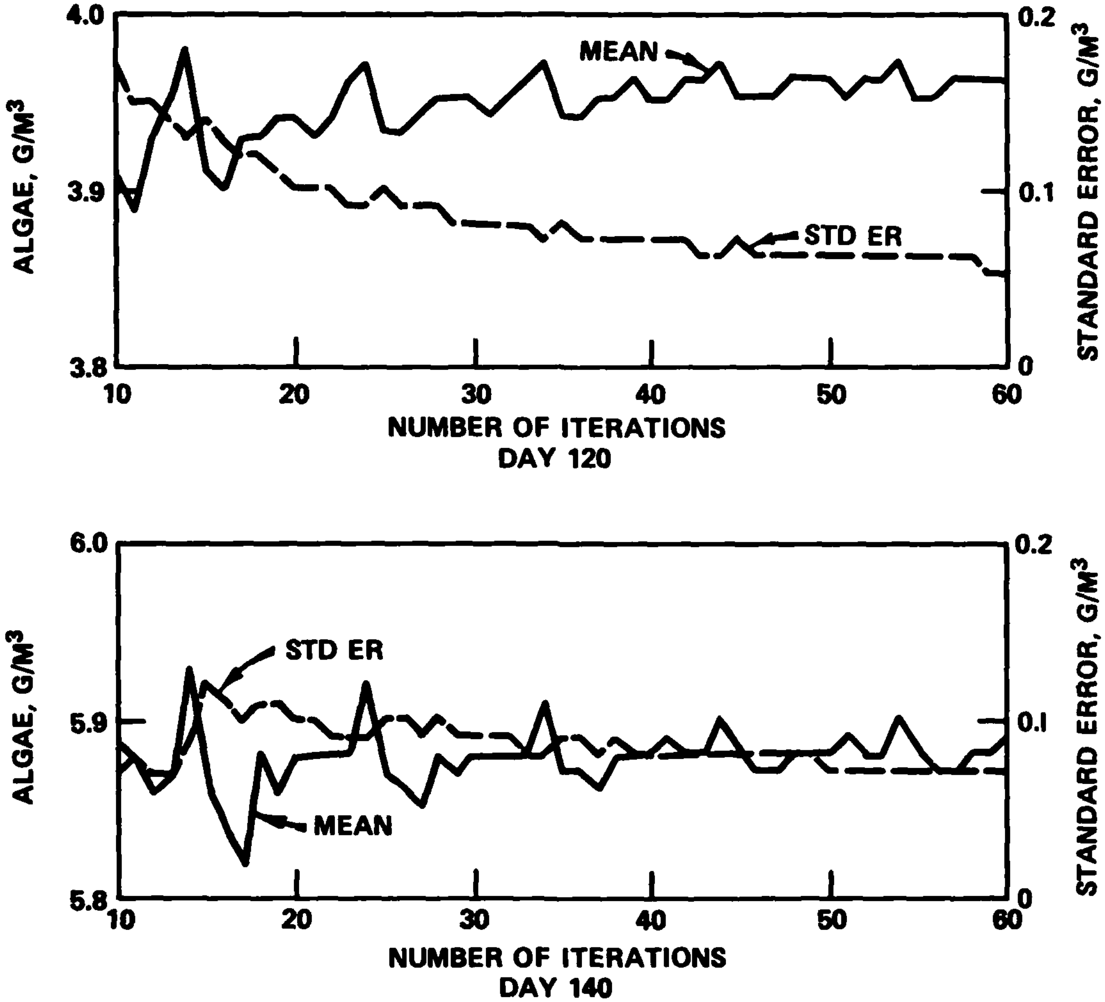



Figure 18. The standard error and mean of algae biomass predictions by Monte Carlo simulation as a function of increasing iterations for simulation days 120 and 140

# SYNOPSIS OF WES EWQOS INVESTIGATIONS TO IMPROVE WATER QUALITY BY GAS TRANSFER TECHNIQUES BOTH IN THE RESERVOIR AND IN THE RELEASE**

By Dennis R. Smith*

## Introduction

Although the epilimnion of a reservoir may be saturated with dissolved oxygen, during late spring and summer density stratification may result in the reduction or depletion of dissolved oxygen in the hypolimnion. Density stratification severely attenuates the vertical transport of dissolved oxygen from the epilimnion to the hypolimnion. Subsequently, oxidation of organic matter and plant and animal respiration in the hypolimnion may gradually produce anaerobic conditions. This not only results in poor water quality in the lower region of the reservoir; it also impacts downstream water quality if hypolimnetic releases are required for flood control or to meet cold water temperature objectives. The Hydraulics Laboratory of the Waterways Experiment Station (WES) has been investigating several techniques to enhance the water quality by gas transfer techniques both in the reservoir and in the downstream release. A synopsis of these investigations is given below.

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** EWQOS - Environmental Water Quality Operational Studies

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## In Reservoir

Both oxygenation and pneumatic destratification techniques have been investigated to assess their potential for enhancing dissolved oxygen levels in the hypolimnion. The results of the oxygenation investigation will be discussed first.

### Oxygenation Study

In 1977, WES initiated a program to study the effects of molecular oxygen injection in the hypolimnion. The purpose of the initial study was to quantify the magnitude of nitrogen stripped from the water column. This study complimented a research effort conducted by other investigators to determine the feasibility of continuous oxygen injection to increase the dissolved oxygen in the hypolimnion. The injection system consisted of a rectangular array or rack mounted diffusers.

Nitrogen concentration profiles were obtained prior to injection and three weeks after injection was initiated. No significant change in nitrogen concentrations occurred in the far field (approximately one mile from the injectors), however, in the near field (approximately 100 ft from the injector) nitrogen concentrations increased significantly. In both the near and far field locations the dissolved oxygen concentrations were enhanced by oxygen injection.

The increase in nitrogen concentration in the near field was apparently the result of the denitrification of sediments entrained in the rising water-oxygen plume. This conclusion is supported by

field observations. The bubble column resulted in substantial pumping which reduced the surface temperatures. Turbidity at the surface indicated significant sediment agitation. The combination of anoxic sediments with oxygenation would cause denitrification and the release of molecular nitrogen which would be absorbed in the water column. At this particular operating condition, a net increase in dissolved nitrogen resulted in the near field. This indicated that localized injection must be carefully designed and operated to prevent the agitation of bottom sediments.

In 1978, WES investigated the feasibility of a line source type of injection system to enhance the DO levels in the hypolimnion of Clark Hill reservoir. The demonstration system was placed on the reservoir bottom perpendicular to the upstream face of the dam. It was approximately 50 ft from the dam and 700 ft from the outlets. It consisted of ten equally spaced 1 $ft^2$ diffusers over a 100 ft length. During injection, turbidity at the surface or significant decreases in surface temperature did not occur. Few bubbles reached the surface from the discrete non-interacting bubble columns. As compared to a rectangular array of rack mounted diffusers, concurrently investigated by others, the line injection system was more effective. It had a higher efficiency and less circulation and sediment agitation was produced by the bubble column.

A full scale injection system is being installed by the Savannah District and South Atlantic Division approximately one mile upstream from the dam and it should be operational during the summer of 1980.

The system will consist of 1/2 $ft^2$ diffusers spaced at 1 $ft^2$ intervals over a 2000 ft length. Background profiles of dissolved gases and temperature were taken in August 1979 in front of the intakes, at the injection site, and approximately two miles upstream the injection system. The effectiveness of the design will be investigated in the summer of 1980.

## Pneumatic Destratification

Pneumatic destratification has been found to be a cost effective method of controlling eutrophication and maintaining water quality in reservoirs. However, it has the potential of producing nitrogen supersaturation. A field study of eleven southern California reservoirs was undertaken during the summer of 1979 to quantify the nitrogen supersaturation produced by pneumatic injection. Ten of the lakes were approximately 20,000 acre-ft and one was 254,000 acre-ft. A wide range of injection rates and geometries were employed in the respective lakes. In some, the injection rate was relatively small and produced only partial destratification. In others, the injection systems produced complete destratification. At each field site, profiles of dissolved oxygen, total gas pressure and temperature were obtained. In the smaller reservoirs, profiles were obtained near the deepest point at three equally spaced time intervals. Data was obtained near the line source diffuser and in the far field of the larger Casitas Reservoir.

In each reservoir, the aeration system increased the dissolved oxygen content of the reservoir. This is particularly evident at Casitas (Figure 1). Prior to installation of the pneumatic aeration system, no measurable dissolved oxygen existed at depths greater than 12.2 meters during summer stratification. Larger quantities of dissolved oxygen were produced at the near field station (approximately 2300 ft from the injector) than at the far field station (12,500 ft). The reduced dissolved oxygen content in the distant reaches from the injector occurs as a result of oxygen depletion mechanism gradually reducing the dissolved levels as the water travels from the injector region.

Although effective in increasing the oxygen content, nitrogen supersaturation with respect to the surface was prevalent in each reservoir. As indicated in Table 1, peak nitrogen supersaturation levels ranged from 104 to 135 percent. In all cases, the magnitude of dissolved nitrogen concentration was less than the potential limits (based upon depth and temperature considerations). In the smaller reservoirs, the concentration tended to decrease with time during the stratification cycle; however, the percent saturation increased. This suggests that the increased temperature associated with partial or complete destratification contributed substantially to the magnitude of nitrogen supersaturation observed.

TABLE 1

PEAK NITROGEN SUPERSATURATION PRODUCED BY

COMPRESSED AIR INJECTION

| Lake | Maximum Reservoir Depth (m) | Peak Nitrogen Saturation |
|---|---|---|
| Casitas | 65 | 135 |
| El Capitan | 42 | 115 |
| Henshaw | 9 | 104 |
| Mathews | 52 | 111 |
| Morena | 25 | 122 |
| Murray | 18 | 112 |
| Perris | 24 | 112 |
| Puddingstone | 18 | 112 |
| Skinner | 23 | 109 |
| Vail | 30 | 122 |
| Wihlford | 19 | 111 |

The vertical distribution of nitrogen concentration in the respective reservoirs was dependent upon the operating conditions. In the small reservoirs which were essentially destratified, the concentration was approximately constant vertically. However, at Casitas which was only partially destratified, the concentration increased gradually with depth

(Figure 1). The nitrogen concentation profiles near injection and in the far field were essentially equivalent. This suggests that it may be possible to control the the nitrogen concentration profile in large lakes by the proper design and/or operation of pneumatic destratification systems.

Some magnitude of nitrogen supersaturation with respect to the surface probably will result from any compressed air injection technique. The magnitude and vertical distribution of nitrogen supersaturation will depend upon the lake size, particular design, degree of stratification and the magnitude of heat transfer to the reservoir. Field studies indicate that nitrogen supersaturation levels will not be prohibitively large, probably less than 135 percent. In the reservoir, nitrogen saturation of this magnitude usually present no environmental problems. However, if nitrogen supersaturation levels in reservoirs are large enough to degrade downstream water quality upon release, it is imperative to use outlet works which degas the release.

## Gas Transfer in Outlet Works

The water quality of the release may be enhanced or degraded by the gas transfer processes that occur during flow through hydraulic structures. Enhancement can be achieved by employing designs which aerate the flow and increase the dissolved oxygen level. However, if nitrogen concentrations are significantly increased, a reduction in water quality may result. As a result, to design environmentally effective hydraulic

structures, techniques are needed to predict the magnitude of gas transfer that occurs during flow through a structure. To develop accurate predictive techniques, it is imperative to identify and analyze the dominant gas transfer mechanisms in various hydrodynamic flow regimes. If this is known, it will be possible to either physically or mathematically model the total gas transfer. Hydraulic model and field studies are being conducted concurrently to achieve this objective.

## Hydraulic Model Studies

Research is being conducted to determine the oxygen uptake which occurs in free hydraulic jumps normally encountered in CE outlet works. To date, hydraulic jumps with unit discharges of 0.414, 0.331, and 0.261 cfs for a range of Froude numbers of flow between 1.8 and 9.3 have been investigated (Figure 2). The oxygen uptake for a particular unit discharge increases linearly for the range of Froude numbers of flow investigated. Similarly, for a particular Froude number, the uptake increases with unit discharge. Hydraulic jumps with larger unit discharges and at higher Froude numbers will be investigated. After these investigations are completed, scaling relationships can be developed to quantatively predict the oxygen uptake and total gas transfer in hydraulic jumps. In the interim, the above results can be used to determine the relative effectiveness of various free hydraulic jump conditions in increasing dissolved oxygen without inducing excessive nitrogen and total dissolved gas concentrations.

Very early in the above test program, it became apparent that the relative oxygen uptake produced as a result of various structural modifications could be investigated in hydraulic models. Tests were conducted in a 1:20-scale model of Lower Monumental Spillway (Snake River) which reproduced a short portion of forebay and a single bay of the spillway section of the dam with the tainter gate for flow control. The stilling basin and a portion of the exit channel were included in the model. Spillway configurations with and without a flip lip on the spillway surface were investigated with a flow rate equivalent to 15,000 cfs in one bay of the prototype. Flow visualization studies indicated a flow phenomenon analogous to prototype observations. Without the flip lip, a plunging flow was observed with large quantities of entrained gas bubbles. The flip lip deflected flow along and near the surface of the tailwater instead of allowing the water to plunge; bubble entrainment was much more localized and near the surface.

The flip lip increased the gas transfer by 37 percent in the model but this does not necessarily imply a 37 percent increase in DO will occur in the prototype. The exact scaling relationship between the model and prototype is still under investigation. It does demonstrate that the flip lip will substantially increase the DO if a deficit exists. Excessive nitrogen supersaturation does not occur with a properly designed flip lip because the gas is transferred between the atmosphere and the released water near the surface and consequently nitrogen concentrations are equilibrated relative to surface conditions. Reduced nitrogen concentrations with a flip lip are not the result of the less total gas transfer.

The above results clearly imply that the relative effectiveness of various structural modifications to improve gas transfer can be investigated in hydraulic models on a site specific basis. Similarly, flow visualization studies can be effectively utilized to qualitatively investigate nitrogen supersaturation potantial. Model studies of specific structures will result in more cost effective designs and should prevent ineffective structural modifications.

Research is also being conducted to comprehensively compare model and prototype data thereby identifying generalized sealing relationships. Model data is being obtained from a 1:20-scale model to Enid Outlet Works. Enid was selected as a result of its unique design. The outlet works trajectory to the stilling basin apron is stepped as compared to the usual parabolic trajectory existing at most CE structures. Field data have been obtained which quantify the gas transfer which occurred as the fluid travelled between specific points in the structure. Thus, the effects of the respective fluid flow processes can be independently determined. This study coupled with the results from the above model investigations will facilitate identification of the dimensionless groupings required to quantitatively scale reaeration occurring in various flow regimes common to reservoir outlet works.

## Hydropower-Turbine Venting

In some hydropower projects, water released from low or mid-level intakes is low in dissolved oxygen during periods of summer temperature

stratification. Turbine venting is one technique which may be used to increase the DO by 1 to 2 mg/l; however, there is an upper limit of 4-5 mg/l DO which can be achieved without resorting to molecular oxygen injection. Air aspiration or injection upstream of the turbine has the potential disadvantage of increasing the dissolved nitrogen concentration in the release. WES has initiated a field study program to determine the magnitude of gas transfer which results from turbine venting.

At J. Percy Priest measurements of DO and total gas pressure were made in the reservoir, penstock, draft tube and approximately 300 ft downstream of the dam in the tailrace. DO in the penstock upstream of the vent was 1.7 mg/l. Venting the turbine resulted in a DO uptake of approximately 2 mg/l between the turbine and the draft tube. However, iron or manganese ions or other oxygen demands in the release resulted in lowering the DO content by approximately 1.5 mg/l from the draft tube to the tailrace. Measurements taken 2400 ft downstream indicated that the DO was approximately 2.0 mg/l. Dissolved nitrogen was approximately 106 percent saturation in the penstock, 110 percent in the draft tube below the turbine chamber, and approximately 112 percent in the tailrace. Similar results were obtained on the small turbine at Allatoona Reservoir. At the scroll cage and in the tailrace 112 and 117 percent nitrogen supersaturation values were measured, respectively. DO increased from 1.8 to 2.9 mg/l. The slightly higher nitrogen concentrations at Allatoona may have been a result of the pneumatic destratification system in the reservoir. Additional field tests are planned in FY 80 to quantify the

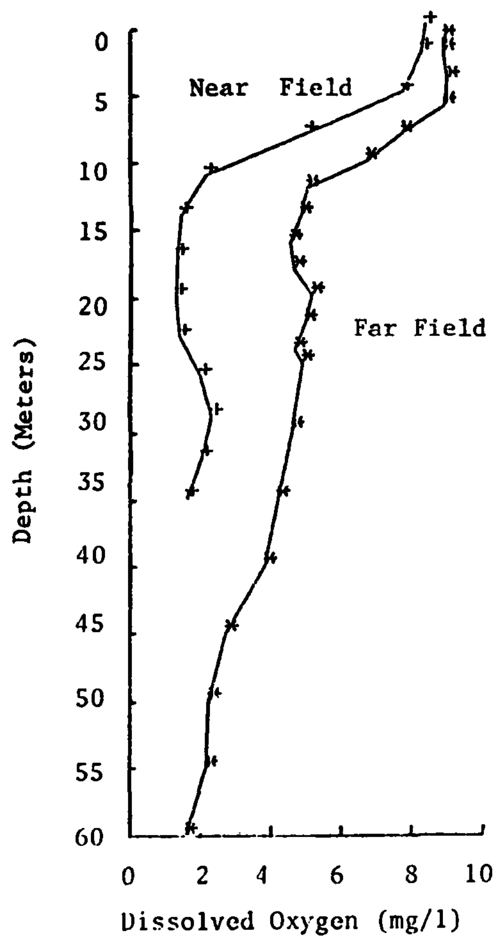
magnitude of nitrogen supersaturation which will result from turbine venting. The results to date indicate nitrogen supersaturation on the order of 112 percent should be expected.

## Conclusions

Oxygenation or aeration techniques can be used to enhance the water quality in the reservoir and/or in the release. As demonstrated at Clark Hill, efficient oxygen injection schemes can be used to increase the dissolved oxygen in the hypolimnion without significantly disturbing stratification. Field results indicate that line injection systems are more effective than rectangular arrays of rack mounted diffusers. If properly designed, a line injection system will inject diffuse noninteracting bubble columns which results in a high gas transfer efficiency and produces minimum circulation. Pneumatic destratification can also be used to increase the DO in the reservoir; however, some degree of nitrogen supersaturation with respect to the surface is likely to occur. Although this may pose no environmental problem in the reservoir, it may necessitate the use of outlet works which degas the release. In some cases, pneumatic destratification will not be a viable alternative as a result of the inherent increase in water temperature.

The released water quality can be improved by employing hydraulic structures which aerate the flow and increase the DO without significantly increasing the dissolved nitrogen concentrations. Techniques have been

developed by the WES Hydraulics Laboratory to assist in designing environmentally effective hydraulic structures. The approach utilizes a coupling of hydraulic modeling, flow visualization and radioactive tracer techniques to determine the relative effectiveness of various outlet work designs and/or structural modifications. Implementation through various site specific model studies will result in more cost effective designs and should prevent ineffective structural modifications.



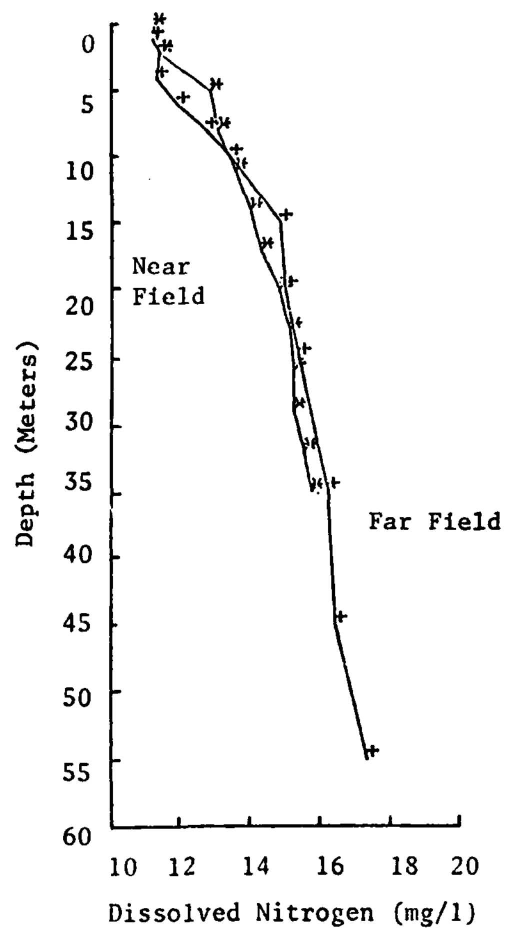




Figure 1. Dissolved Oxygen and Nitrogen Profiles at Casitas Reservoir

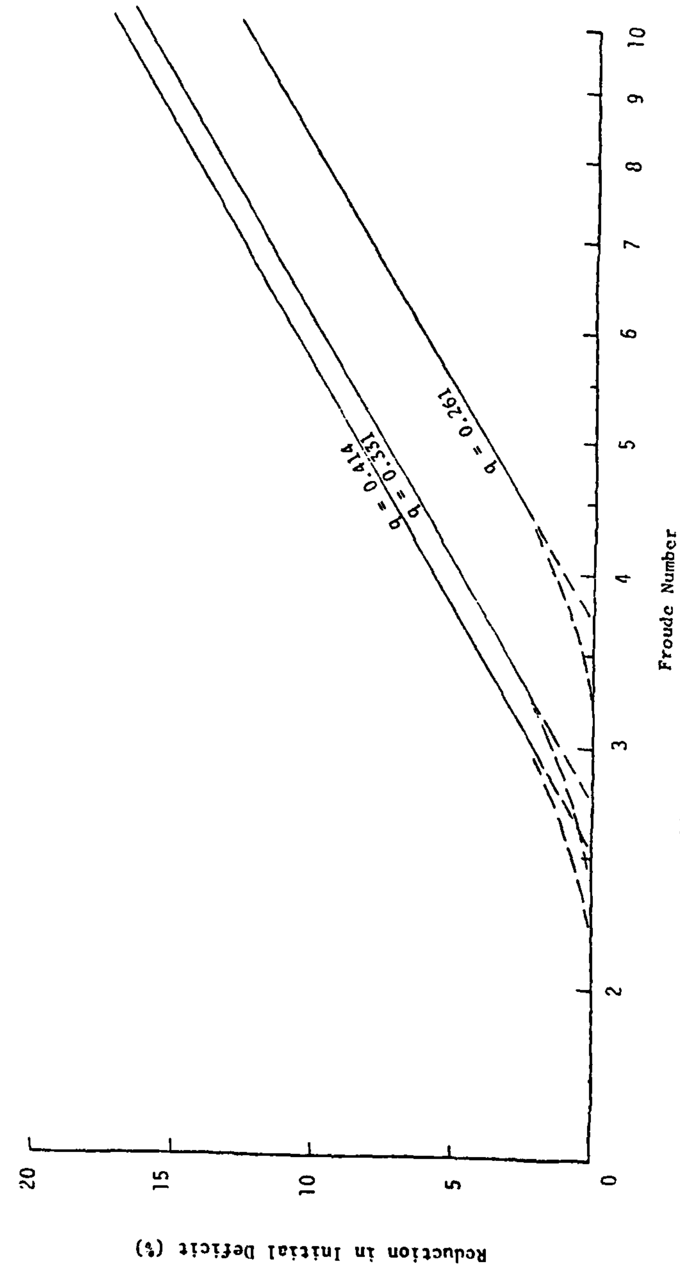



Figure 2. Gas Transfer in Free Hydraulic Jumps at Various Unit Discharges

Figure 2

# ENVIRONMENTAL MONITORING OF THE TAMPA HARBOR DEEPENING PROJECT TAMPA, FLORIDA

BY

LLOYD H. SAUNDERS, PH.D.[1/]

This paper discusses the environmental monitoring that has been performed in Tampa Bay, Florida, to support the Tampa Harbor Deepening Project. A study that was performed by the Corps, at the request of the Port Authority in the late 1960's, found that harbor deepening was economically feasible. The report on that study was submitted to Congress and resulted in project authorization in 1970. The project provides a 43-foot main channel from the Gulf of Mexico into East Bay and branches to Sparkman and Ybor Channels and to Port Tampa (plates 1-4). The project authorization specified in part that, project-related environmental studies be made during the preconstruction planning and construction stages to determine the design and construction practices that will have the minimum adverse effect on the ecology of Tampa Bay and that would enhance existing conditions.

When preconstruction planning commenced on the project, the major problems involved the details of engineering and environmental considerations incident to the excavation and open-water disposal of approximately 73 million cubic yards of material. Of this quantity, about 63 million cubic yards will be removed from the main channels, and about 10 million cubic yards will be removed from the branch channels. To arrive at our present stage of the project has required intensive study, data collection, and coordination between parties with special knowledge. Practical considerations, limitations imposed by technological or natural constraints, and financial resources, all are factors. It is this process of study, design, and coordination, which the Corps of Engineers, as the responsible agency for the Tampa Harbor Project, has endeavored to follow from the beginning.

It was decided early in the planning for the project that monitoring programs would be established to determine the extent, duration, and significance of the impacts generated on water quality, benthos, and marine life by such a massive undertaking. The primary objective of monitoring is to measure and record various biologic and chemical constituents of the Tampa Bay environment before, during, and after construction in areas directly involved in dredge and discharge activity as well as control areas in the Bay. The purpose is to afford comparisons so that reliable assessments can be made of the direct and indirect impacts of dredging and disposal activity on the environment.

The monitoring programs also are intended to provide a means of detecting potential problems resulting from a particular construction activity in time to prevent unacceptable environmental disturbance or damage. In addition, the collected data will provide a valuable information resource for research and study programs on estuarine systems and how they respond to man's activities. The accumulated knowledge could influence direction and design of future dredging contracts in the deepening project.

1/ Chief, Environmental Resources Branch, Engineering Division, Jacksonville District

In the Tampa Harbor Project, monitoring involves a number of different agencies and organizations, a number of different sites within the general Tampa Project area and a number of different techniques and specialized programs. The planning and design of these varied and comprehensive monitoring efforts owe a great deal to the cooperation, advice, and counsel of groups and organizations, such as the Ad Hoc Advisory Committee on the Tampa Project, local environmental groups, the Tampa Port Authority, and the U.S. Geological Survey. In general, the monitoring plans are adapted to the varying levels of environmental concern represented within the overall project area. Thus, the monitoring program for the outer reach of the harbor project is less exacting than those for lower Tampa Bay or for the Upper Hillsborough Bay reach, where environmentally sensitive areas such as marine grass beds or mangroves could be affected by construction.

During 1978 there were three monitoring programs in effect for the Tampa Harbor Deepening Project. Two of these programs covered dredging contracts awarded in Section 1 and Section 2. These sections include the outer reach, the entrance to the bay in the Egmont Key area, and lower Tampa Bay. The third ongoing program is the Tampa Bay Cooperative Monitoring Program which consists of the USGS digital model study of bay circulation and flushing patterns and how they are affected by disposal area design and configuration and circulation cuts. A large sale (1,500-foot grid) model is now being employed. A small-scale (500-foot grid) model is being developed for use on smaller portions of the estuary. Water quality data also is being collected by the Hillsborough County EPC with quarterly reports furnished.

The monitoring programs for dredging in Sections 1 and 2 were handled in the following manner: Sections 1 and 2 have been divided into 3 subsections for construction. The dredging contract awarded on the project was subsection 1A of Section 1. However, the monitoring of this subsection was handled by Corps personnel from the Tampa Area Office. The monitoring consisted of collecting turbidity samples during dredging at 400-foot intervals along the centerline of the turbidity plume at three different depths. A visual description of the appearance and extent of the plume was logged at each sampling. No significant environmental effects as a result of the work have been reported so far. The second contract was for dredging subsection 1B and subsection 2A. The monitoring program in the contract was more extensive and involved turbidity and sediment quality sampling; sampling before, during, and after the placement of dredged material; and sampling of waters near disposal sites, but not apparently affected by dredge-generated turbidity, to provide comparison data. Disposal sites were submergent areas alongside the channel and beach sites on Mullet Key. Open water sampling was performed at three different depths at each location. Monitoring reports showed no significant effects as a result of construction. In addition to water quality monitoring in subsection 2A, an agreement was made with the Tampa Port Authority to perform specialized monitoring in the subsection. During construction activities sedimentation rates in sensitive areas of seagrass beds fronting Mullet Key from Bunces Pass to Madalaine Key were monitored. Data collected was furnished monthly to the Jacksonville District, the Hillsborough County Environmental Protection Commission, the Florida Department of Environmental Regulation, and other agencies who requested it. The results indicated the seagrass beds were relatively unaffected by the work.

The U.S. Geological Survey agreed to perform aerial overflights of the Subsection 2A area and furnish aerial photographs of dredging and disposal sites and sensitive areas on a time-available basis as part of the contract with the Corps for aerial and ground-level monitoring which was to be performed in Section 5. Ground-level sampling for turbidity, suspended sediment, nutrients, pesticies, and trace metals was performed by the Hillsborough County Environmental Protection Commission, by arrangement, with USGS. The ground-level monitoring was coordinated with the aerial over-flights to assure that samples were taken in the turbidity plumes.

Monitoring of Section 5 was considered particularly sensitive to disruption by construction and involved 4 separate data collection efforts. The dredging contractor was required to perform turbidity monitoring at dredging and disposal sites. A separate professional services contract was awarded to monitor dredging and disposal sites within Section 5 for both turbidity and water quality. The contractor also monitored the impact of construction operations on shallow-water ecosystems in Hillsborough Bay. Each location chosen for sampling was sampled along transects extending from mean high water to six feet below mean low water at five evenly spaced sites. Samples were analyzed for turbidity, suspended sediment concentration, and other water quality parameters. Three sets of turbidity and suspended sediment concentration samples were obtained at each disposal site. The contractor furnished daily results of the turbidity sample analyses to the Corps. Results of the water quality sample analyses were furnished every 14 days. Separate reports were compiled for each set of turbidity and water quality samples.

In addition, the U.S. Geological Survey performed a monitoring program in Section 5 to determine spatial and temporal changes in turbidity levels and suspended sediment in channel dredging areas and disposal sites. Sample collection and analyses included areas adjacent to work sites to obtain background data. Samples were collected in dredging plumes at the cutterhead, at the disposal site, and at a location outside the working area and analyzed for nutrients, pesticides, and trace metals. Each of these samples were taken at mid-depth. Turbidity sampling was performed in coordination with aerial overflights. Samples were obtained at 3 depths, 1 foot below surface, at mid-depth, and 1 foot above bottom. Sampling was performed monthly. Collected results, with some interpretation, were furnished on a quarterly basis. An annual report will be made summarizing findings and interpreting all results to date. In addition to aerial photograph interpretation, it is anticipated that photographs furnished by satellite overpass will be available for interpretation and inclusion in the annual or final report.

Sensitive area monitoring, such as that performed in the Mullet Key area by the Tampa Port Authority, is also scheduled for other sites in the project. These include:

<u>Beacon Key</u> - Seagrass beds fronting the southeastern shore of Tampa Bay from the Skyway Bridge to the Little Manatee River.

<u>Interbay</u> - Intertidal and subtidal seagrass beds and mudflats from Port Tampa to Gadsden Point.

Terra Ceia Bay - Mangrove areas in Miguel Bay and Bishops Harbor north to Piney Point.

Cockroach Bay Aquatic Preserve - Mangrove islands and seagrass beds.

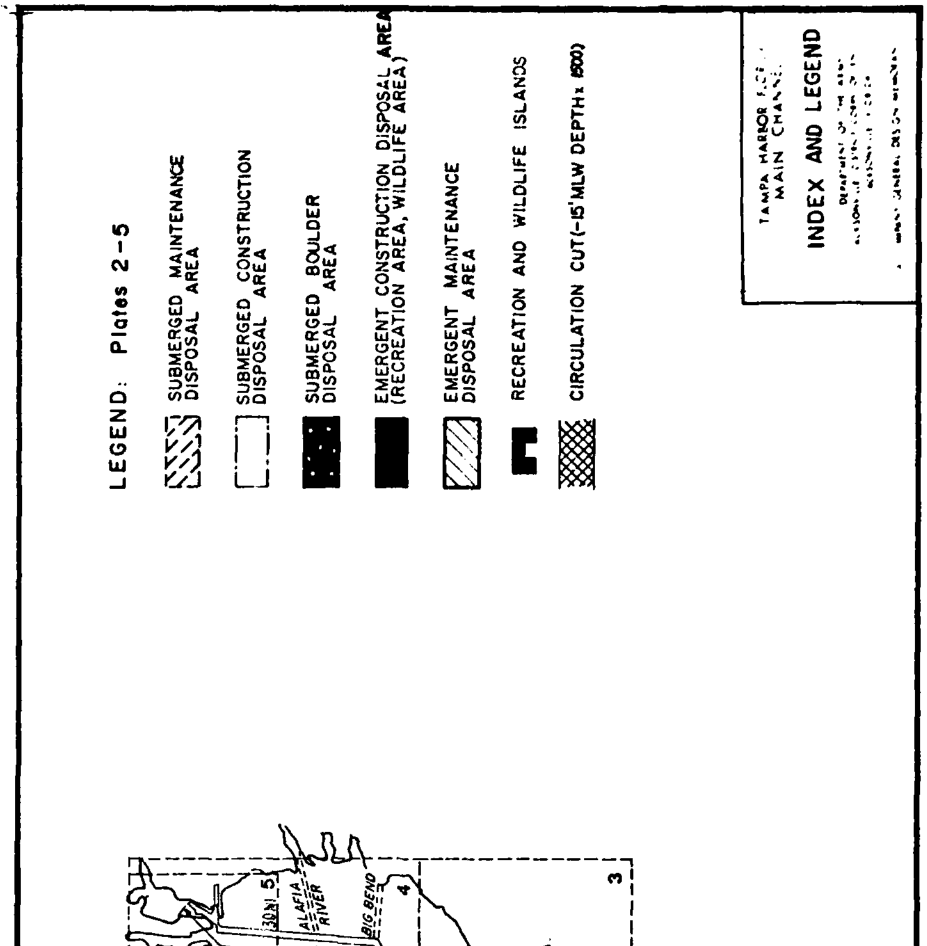
Bullfrog Creek Estuary - Mangrove island and shore between Big Bend and Alafia River ship channels.

Three basic categories of parameters will be sampled: distribution and density of seagrass beds; physical/chemical parameters; and sedimentation rates.

In order to document the impact of the project on benthic organisms and develop guidelines for future dredging contracts, bottom-dwelling invertebrates are being sampled during and following construction activities by a private contractor. Samples are being taken from eight transects, representing all areas of the estuary, at sites selected on the basis of base-line benthic studies completed in 1973. At each designated site, benthic samples will be taken immediately after dredging and again at intervals of six months for at least one year. A comparison of data from this and previous benthic work in Tampa Bay should provide qualitative and quantitative information on the impact of dredging as well as data on invertebrate recolonization and repopulation. When completed, collected data, together with a comprehensive report on the findings, will be available from the Jacksonville District.

The preceding discussion summarizes the environmental monitoring to date. The data collected by the Jacksonville District has been released to the public monthly. It is available for inspection and copying at the office of the Tampa Port Authority.

A construction contract for Section 4 will be awarded in early 1980. The environmental monitoring contract has already been awarded. The monitoring will consist of 48 daily turbidity samples, monthly water quality sampling, and monthly monitoring of three sensitive areas. Monitoring results will be submitted daily and monthly, respectively.



LEGEND: Plates 2-5
SUBMERGED MAINTENANCE DISPOSAL AREA
SUBMERGED CONSTRUCTION DISPOSAL AREA
SUBMERGED BOULDER DISPOSAL AREA
EMERGENT CONSTRUCTION DISPOSAL AREA (RECREATION AREA, WILDLIFE AREA)
EMERGENT MAINTENANCE DISPOSAL AREA
RECREATION AND WILDLIFE ISLANDS
CIRCULATION CUT(-15' MLW DEPTH x 500)
TAMPA HARBOR
MAIN CHANNEL
INDEX AND LEGEND
OLD TAMPA BAY
TAMPA
PORT TAMPA
GADSDEN PT.
TAMPA BAY
ST. PETERSBURG
Sunshine Skyway
MULLET KEY
EGMONT KEY
PORT MANATEE
ALAFIA RIVER
BIG BEND
SECTION 1
SECTION 2
SECTION 3
SECTION 4
SECTION 5


Plate 1

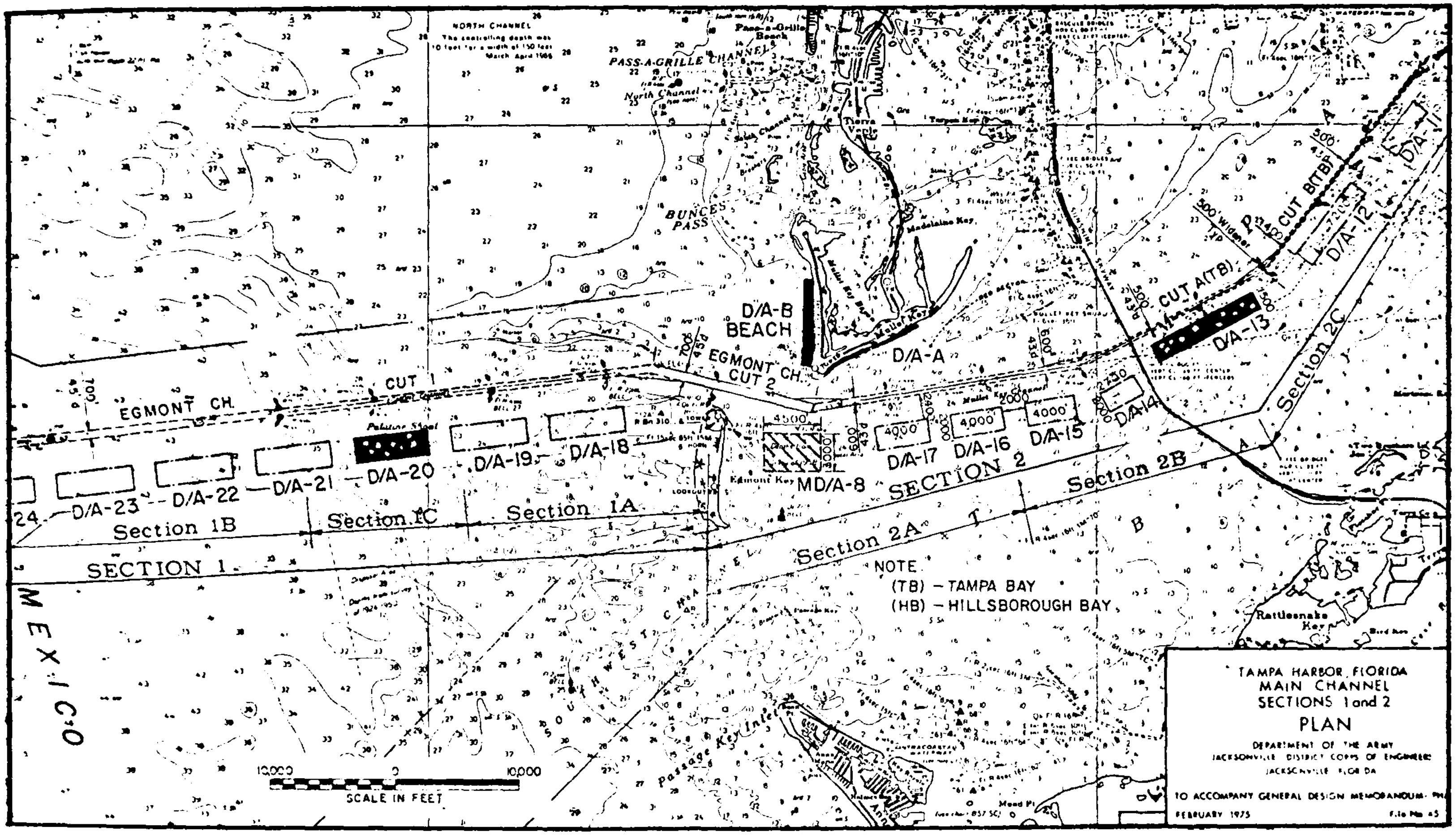
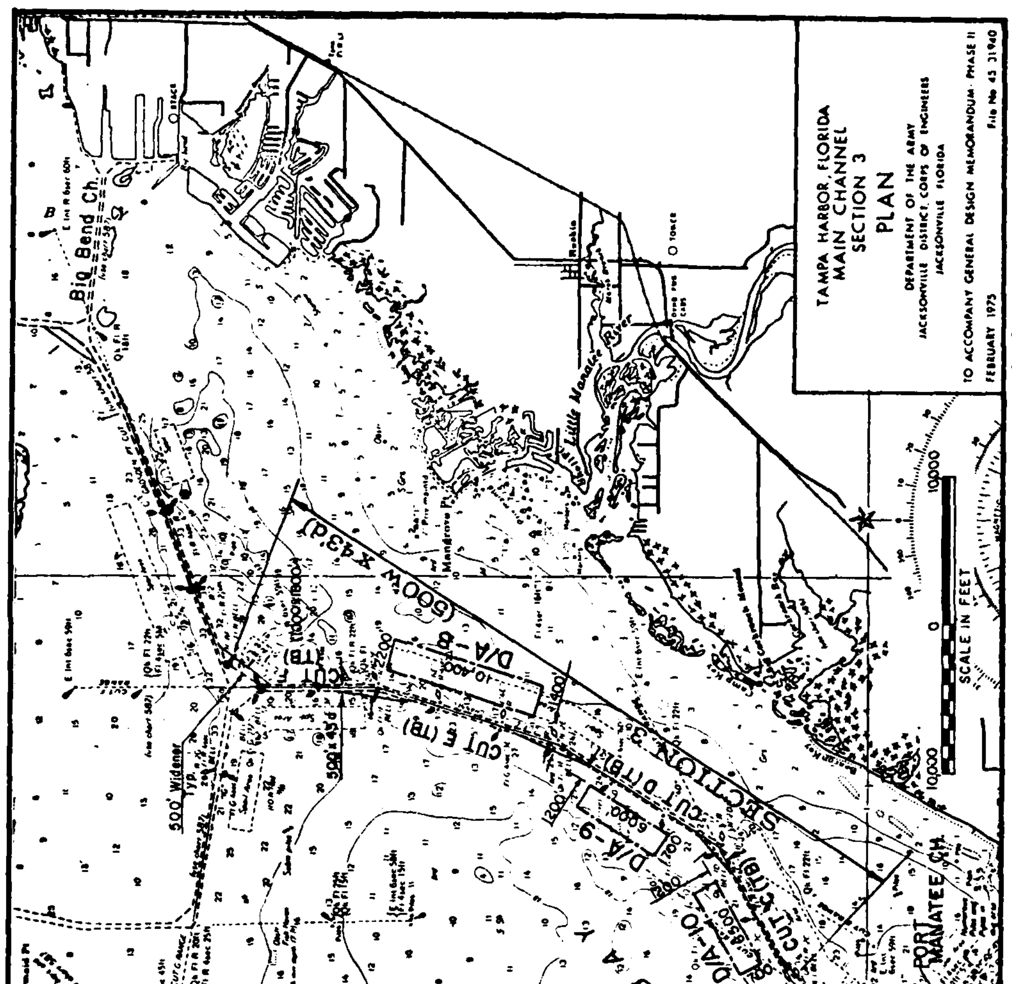
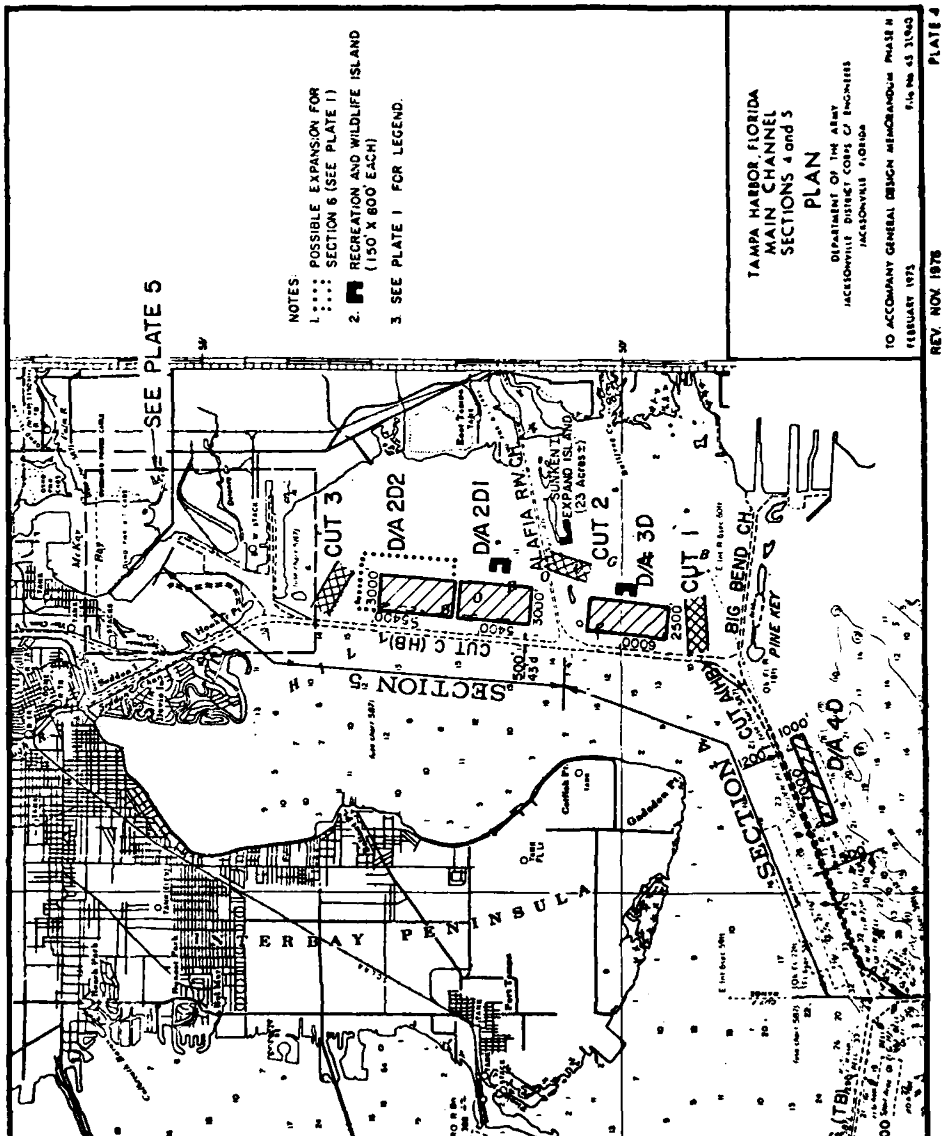

TAMPA HARBOR, FLORIDA
MAIN CHANNEL
SECTIONS 1 and 2
PLAN
DEPARTMENT OF THE ARMY
JACKSONVILLE DISTRICT CORPS OF ENGINEERS
JACKSONVILLE, FLORIDA
TO ACCOMPANY GENERAL DESIGN MEMORANDUM
FEBRUARY 1975
NOTE
(TB) – TAMPA BAY
(HB) – HILLSBOROUGH BAY
SCALE IN FEET
10,000
0
10,000
NORTH CHANNEL
PASS-A-GRILLE CHANNEL
BUNCES PASS
D/A-B
BEACH
EGMONT CH.
CUT 2
D/A-A
EGMONT CH.
CUT
CUT A(TB)
CUT B(TB)
D/A-12
D/A-13
D/A-14
D/A-15
D/A-16
D/A-17
MD/A-8
D/A-18
D/A-19
D/A-20
D/A-21
D/A-22
D/A-23
24
SECTION 1
Section 1A
Section 1B
Section 1C
SECTION 2
Section 2A
Section 2B
Section 2C
MEXICO

Plate 2


TAMPA HARBOR, FLORIDA
MAIN CHANNEL
SECTION 3
PLAN
DEPARTMENT OF THE ARMY
JACKSONVILLE DISTRICT, CORPS OF ENGINEERS
JACKSONVILLE, FLORIDA
TO ACCOMPANY GENERAL DESIGN MEMORANDUM - PHASE II
FEBRUARY 1975
REV. NOV. 1976
PLATE 3
SCALE IN FEET
10,000
0
10,000
SECTION 3
(500'w x 43'd)
D/A-8
D/A-9
D/A-10
CUT E (TB)
CUT D (TB)
500' Widener
Big Bend Ch.
PORT MANATEE CH.
Little Manatee River
T A M P A B A Y
PENINSULA


NOTES:
1. POSSIBLE EXPANSION FOR SECTION 6 (SEE PLATE 1)
2. RECREATION AND WILDLIFE ISLAND (150' X 600' EACH)
3. SEE PLATE 1 FOR LEGEND.
TAMPA HARBOR, FLORIDA
MAIN CHANNEL
SECTIONS 4 and 5
PLAN
DEPARTMENT OF THE ARMY
JACKSONVILLE DISTRICT CORPS OF ENGINEERS
JACKSONVILLE, FLORIDA
TO ACCOMPANY GENERAL DESIGN MEMORANDUM PHASE II
FEBRUARY 1975
REV. NOV. 1976
PLATE 4
SEE PLATE 5
TAMPA BAY
INTERBAY PENINSULA
SECTION 5
SECTION 4
CUT 1
CUT 2
CUT 3
D/A 2D2
D/A 2D1
D/A 3D
D/A 4D
BIG BEND CH.
PINE KEY
ALAFIA RV. CH.
CUT C (HB)
TAMPA CH.
CUT J (TB)
CUT G (TB)
FLA. POWER
WEEDON IS. CH.
SCALE IN FEET

# FOUR RIVER BASINS PROJECT

by

Mann G. Davis [1]

This paper will present a general overview of the Four River Basins, Florida, Project, covering the history and purpose of the project and its status.

The birth of the Four River Basins Project is a familiar story. In the middle 1950's, hot, dry weather brought one of the worst droughts of record to west central Florida. Months passed with little or no rainfall. The water levels in lakes and rivers fell, public water systems were unable to supply enough water to meet the needs of its citizens. Crops failed as irrigation wells went dry. It seemed to some that Florida was on the verge of drying up. But then, the weather pattern began to change. In December, 1958, after four successive months of above average rainfall, the rivers and lakes began filling up and the ground was becoming saturated with water. Florida residents, happy to see that the drought had apparently ended, were unaware that a flood problem lay ahead. Unknown to them, the stage was being set for three successive area-wide floods. The first, occurring in late March, 1959, as a series of severe rain storms caused the full rivers, lakes and streams to overflow their banks, bringing damaging flood waters into many homes, farms and communities. High water remained in many areas of central Florida for two weeks and in some places for as long as two months. Throughout the remainder of 1959, rainfall kept groundwater at abnormally high levels. The above average rainfall continued into 1960, keeping the rivers filled and the ground saturated. Then, in March, 1960, heavy rainstorms again caused wide-spread flooding and extensive property damage; but the worst was yet to come. In September of that year, hurricane Donna struck west central Florida with high winds and heavy rains flooding the area again, for the third time in 18 months. In its wake, 13 were left dead, 144 were hospitalized, 50,000 families were affected and it caused an estimated $200 million in property damage.

In 1961, the State created the Southwest Florida Water Management District with the authority to cooperate with the Federal Government as a local sponsor for flood control and related purposes. Simultaneously, Congress authorized and funded the Corps to investigate the flooded areas and report whether or not a flood control project was economically feasible. The Corps undertook a comprehensive study which resulted in a favorable project. As a result, Congress authorized the Four River Basins Project in 1962. The project was named after the four major rivers within the project area: the Oklawaha, Withlacoochee, Hillsborough, and Peace Rivers. These streams and their tributaries drain about 6,100 square miles. Also included in the report were plans to solve special area problems at Lake Tarpon, the Anclote River and Masaryktown.

[1]Chief, Flood Control Section, Jacksonville District

The Four River Basins Project addresses the majority of the area-wide flood problems through flood detention areas strategically located in the Hillsborough, Withlacoochee, and Little Withlacoochee Rivers and their tributaries. Through the use of levees and control structures, flood waters can be intercepted and temporarily detained until river levels downstream recede. Then the water in these flood detention areas will be gradually released. These FDA's range in size from 10,000 to 59,000 acres.

The Green Swamp, largest of the flood detention areas, is located in portions of Polk, Sumter and Lake Counties and will total almost 59,000 acres. Immediately north of the Green Swamp is the Little Withlacoochee Flood Detention Area which covers 23,500 acres. Southwest of the Green Swamp, in portions of Pasco, Polk, and Hillsborough Counties lies the Upper Hillsborough Flood Detention Area. Further south is the Lower Hillsborough Flood Detention Area. Located entirely within northeast Hillsborough County, it covers over 15,000 acres.

One of two flood detention areas tributary to the Hillsborough River is Cypress Creek which is located in central Pasco County. The other is Blackwater Creek, located near Plant City. The last of the authorized flood detention areas is Jumper Creek on the Withlacoochee River.

The Lower Hillsborough Flood Detention Area, in combination with the Tampa Bypass Canal is the primary protective work for flooding by the Hillsborough River in Tampa. Construction was initiated on this project as early as 1966. The current targeted completion date for all facilities is July 1981. The project would detain floodwaters from the Hillsborough River and divert most flows around the city via the Bypass Canal. The project is designed to protect against the standard project flood.

The Harney Cutoff Canal is designed to siphon off local runoff from the area tributary to the Hillsborough River between the Lower Hillsborough FDA and the Tampa Waterworks Dam. This prevents out-of-bank flows (those in excess of 6,500 CFS) in the highly developed areas downstream of the Waterworks Dam up through standard project flood. This was a post-authorization change to the project in lieu of channel enlargement of the downstream river section.

The Lower Hillsborough Detention Area will function during floods in excess of the mean annual, or about 3,500 CFS. All flows less than that will be discharged downstream through the Hillsborough River. When flows exceed that amount, Control Structure 155 will be closed, the water impounded and released primarily through Control Structure 159 into the Tampa Bypass Canal and thence to tidewater, a distance of about 14 miles. There is a hydraulic head of about 25 feet available during normal conditions in the river, increasing to about 40 feet during the standard project flood. The design discharge through S-159 is 12,000 CFS.

Early design of the Tampa Bypass Canal called for only one control structure between the Lower Hillsborough Outlet (S159) and McKay Bay. This was Control Structure 160. It would prevent salt intrusion upstream and would maintain an optimum water level of elevation 10.0. Since the canal section upstream penetrated the confining layer of the artesian Floridan Aquifer, it was subsequently determined that this level would allow an unacceptable amount of discharge from the aquifer and a lowering of the potentiometric surface in the area. Therefore, an additional structure, Control Structure 162, was added upstream of S-160 in the vicinity of Buffalo Avenue. This new structure would hold seasonal water levels of elevation 12.0 - 15.0 MSL to prevent excessive loss of water from the aquifer.

Because of the nature of the construction with respect to the aquifer, a water level and water quality monitoring program for both ground and surface waters was contracted to the U. S. Geological Survey in July 1974. The purpose of the program was to monitor the effect of the canal construction on the water environment of the area. A network of surface water and ground water sites was designed to monitor changes in nutrients, trace metals, major inorganic constituents, pesticides, and benthic invertebrates along the canal system; to monitor changes in trace elements, common constituents, nitrates, specific conductance, and chlorides in the Floridan Aquifer; and monitor changes in the potentiometric surface of the Floridan Aquifer.

Prior to May 1979, there were no significant changes in the 100 parameters monitored for the ground water and surface water. The greater concentrations of all parameters occur in the surface waters predominated by the ground water. This occurs in the upper portion of the canal system. As you move downstream below S-159 mixing takes place and further downstream the surface water becomes more characteristic of riverine water.

In May of this year the gates at S-161 were opened and the character of the water in the canal changed from typical ground water to typical surface water. That is, it became more acidic and there was a decrease in concentrations of conductivity, alkalinity, calcium, magnesium, sodium, etc., and pH. This can be expected each time the canal is used to divert flood waters from Hillsborough Canal. In summary, there has been no significant changes or trends in surface or ground water quality as a result of construction. However, diversion from Hillsborough River will change the canal's water characteristics from predominantly ground water to typical river water.

Several other important portions of the Four River Basins Project have been completed. One of these is the Lake Tarpon Outfall Canal near Tarpon Springs. The canal, begun in 1966, provides the only surface outlet for Lake Tarpon and flood relief for the lake's many residents. During heavy rainfall periods, flood waters can now be released down the canal through the control structure and into Tampa Bay. The control structure is used to permit lake levels to be fluctuated as necessary to maintain the lake's biological health. It also prevents an excessive lowering of the lake and protects it from salt water intrusion. Prior to the construction of this canal, the lake was interconnected to the Gulf of Mexico via a sinkhole, which has since been diked off.

Another Four River Basins Project which is currently operational is the Masaryktown Canal in Pasco and Hernando Counties. This canal extends 5.5 miles, draining excess waters from the low lying areas of southern Hernando and north central Pasco Counties into Crews Lake. The canal provides flood protection to the community of Masaryktown and surrounding areas.

In Citrus County, the outfall for the Lake Tsala Apopka chain of lakes serves as a surface outlet for the release of excess water from these lakes into the Withlacoochee River. Water control structures allow the careful control of lake levels to prevent flooding of area homes and businesses while maintaining a healthy eco-system in the lakes.

In Marion County, the Moss Bluff Lock and Dam, the J. D. Young Canal, Levee 212 and Kyle-Young Canal were completed between 1967 and 1975. This project provides flood protection for residents in northern Lake and Marion Counties. Originally excavated by private citizens sometime before 1916, the canal allows excess water to flow rapidly from populated areas when necessary while the Moss Bluff Dam prevents excessive lowering of the Oklawaha chain of lakes and adjacent ground water levels. January 1, 1977, this portion of Four River Basins Project became part of the Saint Johns River Water Management District when the Oklawaha Basin was transferred from the Southwest District to the Saint Johns District.

Much has been accomplished on the Four River Basins Project since it was first approved in 1962 and since work began in 1966, but much remains to be done. Investments in the Four River Basins Project total $103.5 million. Of this amount, $72.3 million has been spent on construction and $31.2 million for land acquisition. The Four River Basins Project is well on its way to becoming an important reality and will offer west central Florida effective protection against flooding while at the same time, fulfilling an important role in water conservation.

Recently a new study was conducted to determine if the Four River Basins Project would be modified or extended to include water supply. Called the Four River Basins Water Resources Management Study or WRMS, it is a survey review of the Four River Basins (FRB) Flood Control Project. The survey review was authorized by Congressional resolutions in 1969 and 1970. The focus of the study was to review the Four River Basins comprehensive report with a view to determining whether any modifications of the recommendations contained in the report are advisable in the interest of flood control and water supply. The area of study included all or part of 16 counties in southwest Florida covering about 10,400 square miles with a 1975 population of about 2.2 million people. The Southwest Florida Water Management District has jurisdiction over most of the study area and is the sponsor of the study.

The first phase of the study was problem identification. This phase was characterized by gathering data in each county in the study area, determining existing conditions and water use, then projecting condition and use through the year 2035. From this, the areas of potential future water shortages were identified. The next phase included proposal and formulation of a large number of ways to meet future needs. The options were refined and screened until the 17 most promising alternatives were identified. These were then analyzed using economic, environmental, social and institutional criteria. An evaluation and tradeoff analysis resulted in a ranking of the alternatives by areas to be served.

Generally speaking, well field alternatives ranked higher than surface water alternatives from economic and environmental considerations. Institutional problems exist in varying degrees for most alternatives. Two composite plans were developed from the 17 alternatives to supply needed water for the area through 2035. The report is scheduled for submission in the near future.

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